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Human Infrastructure System Assessment for Military Operations

Understanding the Effects of Infrastructure Changes on Subpopulations

Survey of Current Methods, Models, and Tools

Natalie R. Myers, Angela M. Rhodes, Jeanne M. Roningen, Thomas A. Bozada, Lucy A. Whalley, Susan I. Enscore, Tina M. Hurt, David A. Krooks, Ghassan K. Al-Chaar, George W. Calfas, and Dawn A. Morrison

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and Dawn A. Morrison

Construction Engineering Research Laboratory (CERL)
U.S. Army Engineer Research and Development Center
2902 Newmark Dr.
PO Box 9005
Champaign, IL 61826-9005

Jeanne M. Roningen

Cold Regions Research and Engineering Laboratory (CRREL)
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755-1290

Final Report

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103 Army Pentagon
Washington, DC 20314-1000

Under Project No. 405479, "Human Infrastructure System Assessment for Military Operations"

Abstract

The Army's understanding of infrastructure as an operational variable has been evolving over the past 30 years in response to significant events that range from international conflicts to domestic weather-related disasters. These experiences have combined to drive a significant shift in infrastructure doctrine, which now demands that commanders and staff understand, visualize, and describe the infrastructure variable in order to accomplish the Army's assigned missions of protecting, restoring, and developing infrastructure, all of which are missions essential to restoring stability after conflict or disaster. Current Army doctrine, however, does not say how commanders and staffs are to approach these challenging tasks.

This report provides a focused examination of existing infrastructure assessment methods, models, and tools relevant to commanders' and staffs' growing need for utilizing a holistic analytical capability regarding infrastructure.

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Preface

This study was conducted for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASAALT) under Project No. 405479, "Human Infrastructure System Assessment for Military Operations." The technical monitor was Mr. Ritchie L. Rodebaugh, U.S. Army Engineer Research and Development Center.

The work was performed by the Ecological Processes Branch (CNN) of the Installation Division (CN), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Dr. Chris C. Rewerts was Chief, CEERD-CNN; Ms. Michelle Hanson was Chief, CEERD-CN; and Mr. Ritchie L. Rodebaugh was the Technical Director for Geospatial Research and Engineering, CEERD-TZT. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Abbreviations

Term	Spell-out
A2D2	Anti-Armor Defense Data
ABM	agent-based models
ACAMS	Automated Critical Asset Management System
ADB	Asian Development Bank
ADP	Army Doctrinal Publications
ADRP	Army Doctrine Reference Publications
ANL	Argonne National Laboratory
ANSF	Afghanistan National Security Force
AO	Area of Operations
ASAALT	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASCOPE	areas, structures, capabilities, organizations, people, and events (variables within “civil” mission variable)
ATP	Army Techniques Publication
BCMP	Base Camp Master Plan
CA	Civil Affairs
CAO	Civil Affairs Operations
CAOC	Combined Air Operations Center
CAS	complex adaptive system
CCIR	Commander’s Critical Information Requirements
CENTCOM	Central Command
CGEM	computable general equilibrium model
CI	critical infrastructure
CID	Center for Infrastructure Defense (Naval Post Graduate School)
CIPDSS	Critical Infrastructure Protection Decision Support System
CIVCAS	civilian casualty
CLIOS	complex, large-scale, integrated, open systems
CMO	Civil Military Operations
COA	course of action
COIN	counterinsurgency
DGIWG	Defense Geospatial Information Working Group
DHS	Department of Homeland Security
DoD	Department of Defense
DR	disaster relief
DSCA	defense support of civil authorities

Term	Spell-out
EIA	environmental impact assessment
EWB	Engineers Without Borders
FEST	Forward Engineer Support Team
FM	Field Manual
HA	humanitarian assistance
HDI	Human Development Index
HQ	headquarters
HISA	Human Infrastructure System Assessment for Military Operations
HSIP	Homeland Security Infrastructure Program
IAIA	International Association for Impact Assessment
ICD	Initial Capabilities Document
IED	improvised explosive device
IEISS	Interdependency Environment for Infrastructure Simulation Systems
IESE	Infrastructure and Essential Services Economics
IGO	international governmental organization
IPAR	Infrastructure Portfolio Assessment Review
IR	infrastructure reconnaissance
INFRA	Infrastructure Recovery and Assets Program
ISO	International Organization for Standardization
JIPOE	Joint Intelligence Preparation of the Operational Environment
JP	Joint Publication
LRDC	Long-Range Development Component
MAE	Multi-hazard Approach to Engineering
METT-TC	mission, enemy, terrain and weather, troops and support, time and civil (mission variables list)
MMT	methods, models, and tools
N-ABLE	An Agent-Based Laboratory for Economics
NCIPP	National Critical Infrastructure Prioritization Program
NISAC	National Infrastructure Simulation and Analysis Center
NGO	nongovernmental organization
NSG	National System for Geospatial-Intelligence
OE	Operational Environment
OGX	Open Geospatial Consortium
OPORD	operation order
PIR	Priority Information Requirements
PMESII	political, military, economic, social, infrastructure, and information (operational variables)

Term	Spell-out
PMESII-PT	political, military, economic, social, information, infrastructure, physical environment, and time
REAcct	Regional Economic Accounting
SCADA	supervisory control and data acquisition
SCR	Strategic Country Review
SIA	social impact assessment
SRC	short-range component
SSTR	stability, security, transitions, and reconstruction
SWEAT–MSO	sewage, water, electricity, academics, trash–medical, safety, other considerations (major areas within the infrastructure assessment survey)
TCAPF	Tactical Conflict Assessment and Planning Framework
TRADOC	Training and Doctrine Command (U.S. Army)
UN	United Nations
UNEP	United National Environmental Program
USACE	U.S. Army Corps of Engineers
USAID	United States Agency for International Development
U.S.C.	United States Code
USG	U.S. Government
USMA	U.S. Military Academy

1 Introduction

1.1 Background

Unintended consequences arise when key infrastructure is destroyed or when inadequate infrastructure fails to support local populations. This is because infrastructure systems function within complex social, political, economic, and environmental contexts. Joint Publication (JP) 3-0, *Joint Operations*, depicts this environmental context with Figure 1 by identifying those aspects of the operational environment that may differ from one operational area to another and affect operations. Detailed understanding and characterization of the nodes and links between the environmental variables remains largely unknown. The Army identifies this gap as a shortfall in "U.S. Army Functional Concept for Engagement" (TRADOC Pam 525-8.5, 25):

> Future Army forces require the capability to integrate knowledge of the theater environment, such as culture, terrain, weather, infrastructure, demographics, and neutral entities, in particular, understanding the perceptions of partners and other human elements of the environment to develop the situation through action and exert psychological and technical influence.
>
> Future Army Forces require the capability to conduct analysis of political, military, economic, social, infrastructure, and information aspects of the operation at all echelons to allow commanders at all levels to conduct operations in a decentralized manner in cooperation with partners.

The force currently lacks the capability to quickly interpret how interactions between physical infrastructure conditions and human environments impact military operations and mission accomplishment. The Army's payoff for building such a capability is the ability for commanders to be proactive with better, more informed decisions during the mission planning process—reducing unintended consequences and increasing the effectiveness of infrastructure interventions to achieve overall mission objectives.

Figure 1. Operational environment variables (JP 3-0, IV-5).

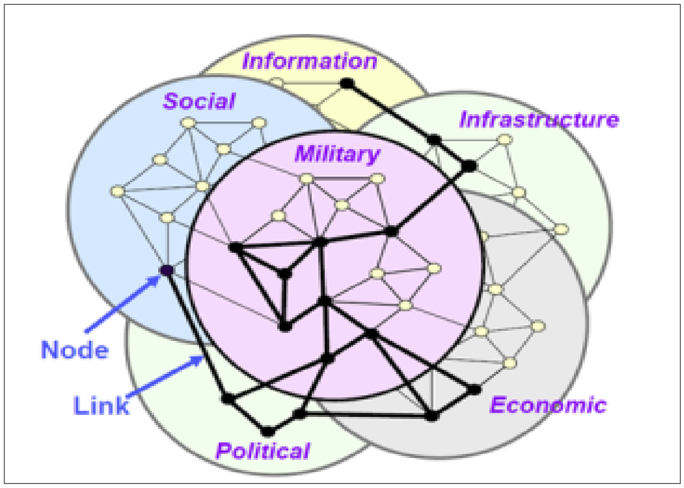


Figure 2 conceptualizes the linkages between infrastructure and society. The beliefs and behaviors that a population has toward infrastructure shapes its physical form. In turn, the physical form of infrastructure drives population behaviors. Absent outside events, these two contexts influence each other until equilibrium is reached. Issues arise when there is long-term lack of benefits to one or more identity groups or when a sudden change occurs because of crisis or conflict. Of interest to this effort is what happens when U.S. forces are the agent of change—destroying, preserving, or rebuilding a piece of infrastructure during military operations. These actions can have unintended consequences that have a negative resulting effect on society, which in turn puts the military operations at risk.

The skill, ability, and knowledge to understand and quantify the effects that infrastructure changes (e.g., destroy, preserve, rebuild) have on combined physical and social conditions is the capability needed to understand this problem space and meet Army requirements. Table 1 references additional joint and Army publications that are relevant to the Human Infrastructure System Assessment (HISA) for military operations.

Figure 2. The problem space between infrastructure and society (ERDC-CERL).

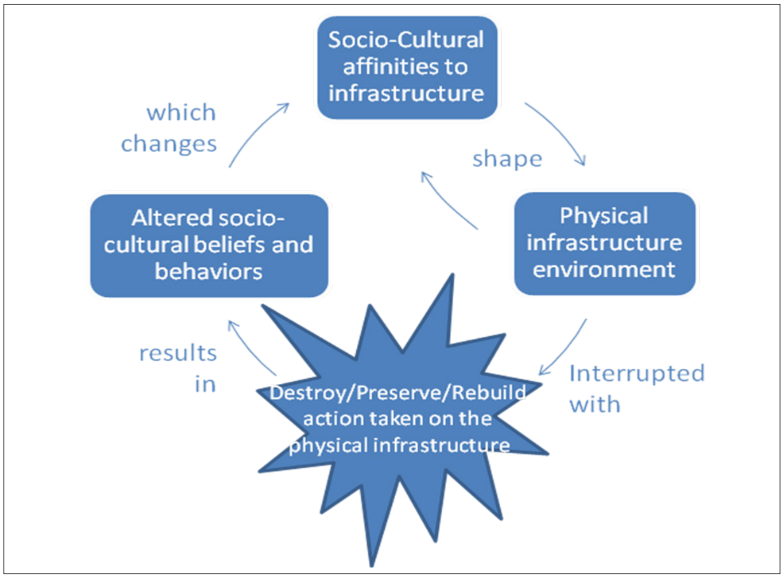


Table 1. Other military doctrinal requirements relevant to HISA.

Document	Requirement
TRADOC PAM 525-66, “Force Operating Capabilities”	(MC-11) Inform and Influence Activities
	(INT-1) Holistic Human and Societal Assessment
	(INT-4) Data-to-Decision Processing, Exploitation and Dissemination
	(INT-6) Collection Synchronization
TRADOC Pam 525-3-7, “The U.S. Army Human Dimension Concept”	Capability to sense, monitor, and record activity (behaviors, characteristics, and others) about persons, places, or things.
	Capability to integrate knowledge of the theater environment such as culture, terrain, weather, infrastructure, demographics, and neutral entities.
	Capability to work with unified action partners to build the capacity to secure populations, protect infrastructure, and strengthen institutions as a means of protecting common security interests.
TRADOC Pam 525-2-1, “U.S. Army Functional Concept for Intelligence 2016–2028”	Capability to conduct analysis of political, military, economic, social, infrastructure, and information (PMESII) aspects of the OE.
TRADOC Pam 525-8-5, “U.S. Army Functional Concept for Engagement”	Capability to integrate knowledge of the theater environment, such as culture, terrain, weather, infrastructure, demographics, and neutral entities, in particular, understanding the perceptions of partners and other human elements of the environment to develop the situation through action and exert psychological and technical influence.

1.1.1 The Human-Infrastructure System Assessment work package

The HISA research and development work package is a three-year effort (2014–2016), with the objective to integrate existing methods, models, and tools to produce new interdisciplinary knowledge to improve the analytical capabilities available for the Army user regarding sociocultural behaviors and infrastructure interdependencies. The goal is to advance an integrated understanding of the human–infrastructure relationship.

The first year of the effort (2014) focused on the state of the science and evaluating how existing methods, models, and tools can meet the HISA objective. The work's report, *Infrastructure and the Operational Art* (Hart et al. 2014), provided a framework for thinking about this problem. It discussed how commanders and staffs may think critically, creatively, and completely about infrastructure problems.

The second year of the effort(2015) integrated societal use of infrastructure with physical infrastructure interdependency modeling to form a new analytical tool that calculates the effects on a society of infrastructure changes. Several case studies facilitated the tool development. This 2015 report provides a focused examination of existing infrastructure assessment methods, models, and tools relevant to commanders' and staffs' requirement for a holistic analytical capability regarding infrastructure.

The final year (2016) will complete development and use Army scenarios to validate the tool knowledge. A subsequent report is anticipated to describe a new analytical tool that calculates the effects of infrastructure changes on subpopulations, with case study examples.

1.2 Objectives

The objectives of this report were to:

1. Describe and develop background on existing infrastructure and sociocultural assessment methods, models, and tools relevant to understanding the relationships between infrastructure and society in the context of the operational environment.

2. Describe, drawing on existing research, potential opportunities and challenges concerning an integrated understanding of the human-infrastructure relationship.

1.3 Approach

This work was accomplished in the following steps:

1. An interdisciplinary team (composed of engineers and social scientists) was formed to review the wealth of infrastructure assessment methods, models, and tools (MMT) from both the engineering and sociocultural perspectives. MMTs were identified from academic, practitioner, and military literature.

2. Team members then took a broad, strategic, and forward-minded look (as described in Hart et al. 2014) at how existing capabilities can be used to build the skills, abilities, and knowledge necessary to understand the effects that infrastructure changes have on subpopulations. This review also includes key challenges in bringing existing MMTs together as a holistic assessment methodology.

2 Definitions and Army Doctrine

Since shared definitions and understandings are essential to the description and development of a background, the terms infrastructure and operational environment are defined here, along with a discussion on what Army doctrine says about infrastructure in the operational environment.

2.1 Definition of infrastructure

The word infrastructure has many definitions, each tailored to the particular perspective of the author. Each is correct for the needs of the author but in a broader, conceptual sense, multiple definitions taken together are necessary for a complete understanding.

- The U.S. Army states in ADRP 3-0 that infrastructure "is composed of the basic facilities, services, and installations needed for the functioning of a community or society."

- The Department of Homeland Security (DHS), in the National Infrastructure Protection Plan, uses a broader definition: "The framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, the smooth functioning of government at all levels, and society as a whole. Consistent with the definition in the Homeland Security Act, [1] infrastructure includes physical, cyber, and/or human elements" (DHS 2013).

- James Carlini took a business-focused approach and defined infrastructure as "a platform for commerce and economic growth" (Carlini 2009, slide 7).

Considering the above definitions of infrastructure, the following critical elements of infrastructure emerge:

[1] The Homeland Security Act was enacted 25 November 2002 by the U.S. Congress in the wake of the 9/11 terrorist attacks on U.S. soil (Public Law 107-95, 116 Stat. 2135).

- **Infrastructure is the mechanism that delivers the fundamental needs of society**: food, water, energy, shelter, governance. Very simply, without infrastructure, societies disintegrate and people die.

- **Infrastructures are, by definition, networks**. These infrastructure networks are inter- and intra-connected and dependent systems. Failure of a small number of elements in the infrastructure can cause the entire system to fail. Additionally, failure in elements of one infrastructure can cascade to another dependent infrastructure.

- **Infrastructure is the platform on which the economy functions and prosperity depends**. Infrastructure supports essential economic functions such as production, transportation, communications, payroll, and employment.

2.2 Definition of the operational environment

An operational environment is "a composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander" (ADRP 3-0, 1-1, paragraph 1-2). An operational environment may be described through the use of operational variables, namely "those aspects of an operational environment, both military and nonmilitary, that may differ from one operational area to another and affect operations. Operational variables describe not only the military aspects of an operational environment but also the population's influence on it" (ADRP 3-0, 1-1, paragraph 1-2). The Army employs the six joint operational variables: political, military, economic, social, information, and infrastructure, and to these it adds physical environment, and time. These eight variables are often abbreviated as PMESII-PT. While conceived for military operations, these variables are also useful in understanding societies outside of conflict zones if the "military" variable is replaced with public safety, security, or emergency services.

2.3 How Army doctrine works

It is helpful to review how current Army doctrine is organized. Army doctrine provides an overview of: what the Army does, how it is organized, how it approaches military operations, how it understands the operational environment, and how it plans and executes military operations and

tactics, procedures, and techniques for accomplishing its warfighting missions.

Doctrine exists to provide a foundational understanding of the Army and how the Army operates, with the intent that all Army personnel, uniform and civilian, interpret army guidance and orders in the same way. Currently Army doctrine is organized according to four major categories of information: Army Doctrinal Publications (ADPs), Army Doctrine Reference Publications (ADRPs), Field Manuals (FMs), and Army Techniques Publications (ATPs).

2.3.1 Army Doctrinal Publications (ADP)

The highest level of doctrine is an ADP. ADPs establish the fundamental principles of Army Doctrine. There are 16 ADPs, beginning with ADP 1, "The Army." A total of 14 of the 16 ADP are relevant to understanding the role of infrastructure in military planning and operations, and these 14 ADPs are listed below.

The six ADPs marked in bold correspond to six of the seven warfighting functions.[2] Five of those six ADPs have titles that directly correspond to warfighter functions, and ADP 3-90 (titled "Offense and Defense") covers the function "Movement and Maneuver." The seventh warfighting function, "Engagement" was established in 2014.

- ADP 1, The Army
- ADP 1-01, Doctrine Primer
- ADP 1-02, Operational Terms and Military Symbols
- **ADP 2-0, Intelligence**
- ADP 3-0, Unified Land Operations
- ADP 3-05, Special Operations

[2] A *warfighting function* is a group of tasks and systems (people, organizations, information, and processes) united by a common purpose that commanders use to accomplish missions and training objectives" (ADRP 3-0, page 3-2, para 3-6). The seven warfighting functions are: Intelligence, Movement and Maneuver, Fire Support, Protection, Sustainment, Command and Control, and Engagement.

- ADP 3-07, Stability
- **ADP 3-09, Fires**
- ADP 3-28, Defense Support of Civil Authorities
- **ADP 3-37, Protection**
- **ADP 3-90, Offense and Defense**
- **ADP 4-0, Sustainment**
- ADP 5-0, The Operations Process
- **ADP 6-0, Mission Command**

2.3.2 Army Doctrine Reference Publication (ADRP)

The intent of an ADP, as described above, is to explain the fundamental principles of the subject. ADPs are intended to be relatively brief, and most ADPs are supported by an ADRP. The ADRP provides a more detailed explanation of doctrinal principles than its corresponding ADP. ADRPs have accompanying interactive media instruction programs that guide the reader through the key points of the ADP and ADRP with graphics, videos, voice-overs, and quizzes to test knowledge of the subject.[3]

2.3.3 Field Manual (FM)

The next level of detail is provided in Army FMs. FMs provide principles, tactics, and procedures to how the Army executes operations described in the ADP and ADRP. Tactics are defined in Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms* as "the employment and ordered arrangement of forces in relation to each other." Tactics are found in the main body of the FM. "Procedures" are defined by JP 1-02 as "standard, detailed steps that prescribe how to perform specific tasks." Procedures are found in the appendices of the FM. Procedures are found in the appendices.

[3] http://usacac.army.mil/core-functions/doctrine/multimedia-resources

There are more than 50 FMs. The FMs are grouped by the following themes:

- Decisive Action
- Warfighting Functions
- Reference Publications
- Branches (of the Army)
- Types of Operations and Activities
- Other Echelons
- Special Category

2.3.4 Army Techniques Publication (ATP)

The final tier of Army doctrine is the ATP. The modern operational environment is complex and dynamic. To be successful, the Army must learn and rapidly adapt to changing situations. ATPs support this type of adaptive learning by providing both departmentally approved publications and a wiki site for direct contributions by any soldier.[4] Both resources are managed by an assigned proponent who is responsible for monitoring input via the wiki and approving changes to approved documents. This proponent ensures consistency with doctrine and provides quality control of content.

As can be inferred from their name, ATPs contain "techniques." JP 1-02 defines "techniques" as "non-prescriptive ways or methods used to perform missions, functions, or tasks." Techniques are the most dynamic and changeable element of doctrine. There is no limit to the numbers of the techniques.

2.4 What doctrine says about infrastructure

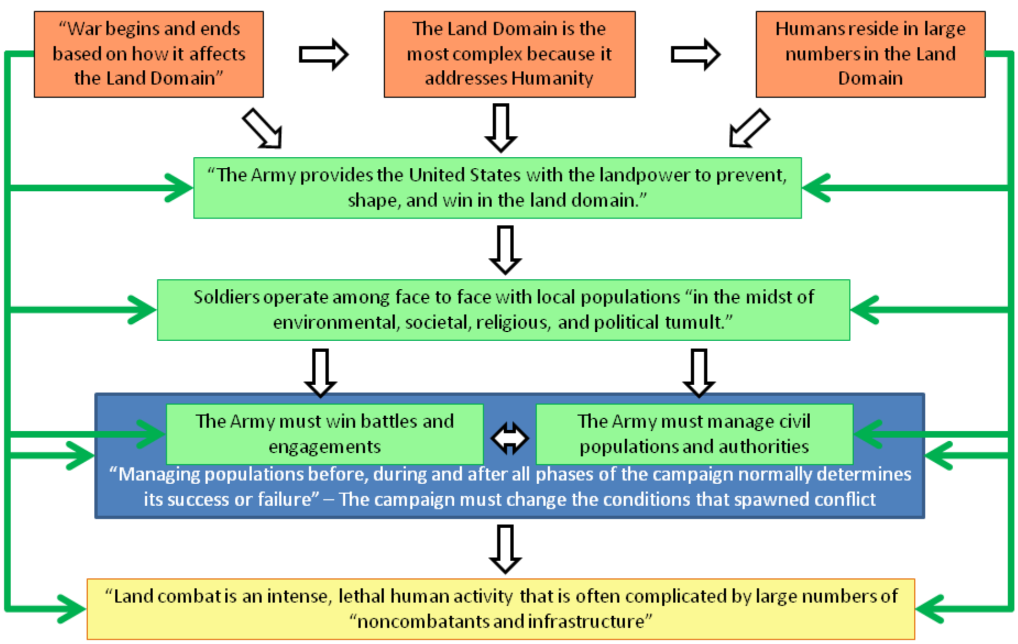
This section summarizes the explicit and implicit treatment of infrastructure by ADP 1, *The Army* and by ADRP 1, *The Army Profession*. ADP 1 frames how Army soldiers and civilians think about the strategic

[4] https://www.milsuite.mil/wiki/Portal:Army_Doctrine. (NOTE: this site is restricted to DoD personnel.)

environment, develop and refine doctrine, and chart a future course. The preparation of ADP 1 is under the direction of the Army's Chief of Staff and gives his vision for the Army; it provides a context for what the Army is, what it seeks to accomplish, and how it accomplishes its tasks. To do that, ADP 1 also gives the Army's mission, purpose, and roles as they are defined by the Constitution, public law, and the Department of Defense (DoD).

Unfortunately, Army doctrine does not explicitly describe the "chain" that begins with the Army's mission and ends with its need for understanding infrastructure. However, ADP 1 begins articulating the key concepts (links in the chain) that can be restated as the "Army mission to infrastructure chain," as shown in Figure 3.

Figure 3. Doctrinal foundation for infrastructure in Army operations (ERDC-CERL with quotations from ADP 1,).



2.4.1 Why infrastructure is important

The following italicized passages are taken from ADP 1 (paragraph 1-1) and are followed by bulleted comments from this report's authors of what the passage means with respect to infrastructure.

- "*War begins and ends based upon how it affects the land domain.*"

  - Establishes the relationship between war and the land domain.

- "*The land domain is the most complex of the domains, because it addresses humanity—its cultures, ethnicities, religions, and politics.*"

- *"The distinguishing characteristic of the land domain is the presence of humans in large numbers."*

  - Establishes the linkage between the land domain and people.

- "*The Army provides the United States with the landpower to prevent, shape, and win in the land domain.*"

  - The reason the Army exists is to "prevent [war], shape [events], and [if, necessary] win [wars] in the land domain" while in the "presence of humans in large numbers."

- "*Humans live on the land and affect almost every aspect of land operations. Soldiers operate among populations, not adjacent to them or above them. They accomplish missions face-to-face with people, in the midst of environmental, societal, religious, and political tumult."*

  - Soldiers must operate among populations and consider local populations to accomplish missions.

- *"Winning battles and engagements is important but alone is usually insufficient to produce lasting change in the conditions that spawned conflict. Our effectiveness depends on our ability to manage populations and civilian authorities as much as it does on technical competence employing equipment. Managing populations before, during, and after all phases of the campaign normally determines its success or failure. Soldiers often cooperate, shape, influence, assist, and coerce according to the situation, varying their actions to make permanent the otherwise temporary gains achieved through combat."*

  - The Army must not only win battles and engagements but it must also manage populations and civilian authorities during all phases of a campaign to produce lasting change in the conditions that spawned conflict in order that the temporary gains achieved through combat become permanent.

- “…all phases of the campaign” implies that actions that address, impact, or influence local populations and civilian authorities must be considered geospatially and longitudinally across the phases.

From ADP-1, page 1-2, paragraph 1-4:

- *“Land combat against an armed adversary is an intense, lethal human activity. Its conditions include complexity, chaos, fear, violence, fatigue, and uncertainty. The battlefield often teems with noncombatants and is crowded with infrastructure.”*
    - Land combat is “an intense, lethal human activity” that is often complicated by large numbers of “noncombatants and infrastructure”.
    - This first reference to infrastructure is stated on the second of 34 pages of the main body of the Army capstone doctrinal publication.[5]
    - This passage strongly implies that infrastructure must be considered during military operations.

2.4.2 How infrastructure is important

If the preceding section describes “why” the consideration of infrastructure is important to the Army, ADP 1 also begins to establish the foundations for “how.” Para 1-5 introduces the concept that an overall mission is typically a combination of combat, governance, and civil security missions and generally utilizes a combination of lethal and nonlethal actions. These combinations highlight the nature of modern warfare in which combat operations usually take place in the midst of noncombatants. Nonlethal missions include disaster relief and humanitarian assistance. Sometimes conflict itself creates the need for

[5] The word “infrastructure” appears in ADP 1-0 only four times, and only three of the four times relate to host nation infrastructure. ADRP 1-0 contains no instances of using the word “infrastructure.”

humanitarian assistance,[6] and sometimes the need for humanitarian assistance requires kinetic actions to create the conditions where assistance can be delivered.[7]

2.4.3 Who the Army must work with

Paragraph 1-6 begins to establish "who" the Army must work with when implementing activities where infrastructure considerations may be critical for successful conclusion of the operational mission. Army forces must synchronize operations with:

- other military services within the DoD (joint),
- other U.S. government agencies (interagency),
- other international partners (intergovernmental),
- and military forces from partner nations.

In other words, the Army must be able to conduct "unified land operations is that Army forces combine offensive tasks, defensive tasks, stability tasks, and defense support of civil authorities (DSCA)[8] in concert with joint, interagency, intergovernmental, and multinational partners" (JP 1-02, 68).

This paragraph also introduces three types of tasks for the Army: Offensive, Defensive, and Stability. The first two tasks are inherently kinetic and the last is nonkinetic, and these three tasks are typically executed concurrently in a proportion appropriate for the unique mission. The proportion will vary over time as the situation changes. This paragraph also lists the various partners that the Army will likely work with. The role of infrastructure is fundamentally different for each of these

[6] An example of a conflict that requires humanitarian assistance is the large numbers of civilians displaced by the Syrian Civil War, which started as pro-democracy protests in early 2011. As of 2 September 2014, the United Nations High Commissioner for Refugees reported the number of registered Syrian refugees was close to three million people with another 35,360 waiting to register. (Source: http://data.unhcr.org/syrianrefugees/regional.php)

[7] The early August 2014 U.S. airstrikes against the Islamic State in Iraq and Syria were in support of humanitarian assistance to Yezidi refugees on Mount Sinjar, in northwest Iraq. (Source: http://www.defense.gov/Releases/Release.aspx?ReleaseID=16880)

[8] When DoD assets support civilian authorities in civil emergencies on U.S. soil, it is known as DSCA.

tasks. These differences will be addressed later in the second part of this investigation.

Paragraph 1-7 of ADP 1 further expands the interaction between the Army and the civilian agencies of the United States Government (USG). These other USG agencies depend on the Army to create the secure environment necessary for agencies to work with local leaders to address whatever conditions led to the conflict. Similarly, the Army depends on the USG civilian agencies to provide resources and expertise for reconstruction of facilities in war-torn regions in order to relieve soldiers of the responsibility for caring for noncombatants. It is a key point that while civilian agencies provide the expertise needed to address core issues that created the unstable conditions, these agencies work primarily in permissive, not combative, environments. Therefore, Army forces must still conduct “human engagement” with local authorities and populations in those areas where civilian agencies cannot freely operate. Ultimately, Army forces must create the conditions where the transfer of responsibilities back to USG civilian agencies and the host nation is possible.[9] Army actions early in an operation or campaign significantly influence the amount of effort and degree of difficulty in making the transition.

The next section of ADP 1, “Landpower for the Nation,” introduces additional key material. “Landpower” is defined as “the ability—by threat, force, or occupation—to gain, sustain, and exploit control over land, resources, and people” (ADP 1: page 1-4, para 1-8 and ADRP 3-0: page 1-7, para 1-42). This definition shows that ADP 1 makes a direct reference to resources and people. Resources should be interpreted broadly to include built infrastructure and natural infrastructure. People should be interpreted broadly to include friendly, neutral, and threat personnel. In this context, the term “control” includes the exercise power and authority

[9] JP 3-0, Joint Operations, 11 August 2011, page V-9. Under the Joint Phasing Model, Phase IV is ‘Stabilize” and Phase V is “Enable Civil Authority”. Stability operations *“help reestablish a safe and secure environment and provide essential government services, emergency infrastructure reconstruction, and humanitarian relief.”* Phase IV and V transition control back to civilian authorities.

but also to oversee and manage (ADP 1-02: page 1-14).[10] Therefore, control of people includes two understandings: (1) that people have the ability to provide for their basic needs and services, and (2) that people have a reasonable ability to conduct their affairs.

Because infrastructure plays a large role in providing for basic needs and enabling civil and economic activities, destruction, or otherwise restricting use of infrastructure by populations the army is trying to control will negatively influence a neutral population's beliefs and possibly its behaviors. Infrastructure restrictions will also require the ground commander to divert planning, logistics, and personnel to meet the responsibilities to feed, shelter, and care for local populations.

Paragraph 1-42 also includes critical amplification of the meaning of landpower with five bullet points that delineate five abilities of landpower:

- *Impose the Nation's will on an enemy, by force if necessary.*

- *Engage to influence, shape, prevent, and deter in any operational environment.*

- *Establish and maintain a stable environment that sets the conditions for political and economic development.*

- *Address the consequences of catastrophic events—both natural and man-made—to restore infrastructure and reestablish basic civil services.*

- *Secure and support bases from which joint forces can influence and dominate the air, land, and maritime domains of an operational environment.*

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[10] The term "control" has four joint doctrinal meanings and three Army doctrinal meanings. Three are relevant in this context: *"1. Authority that may be less than full command exercised by a commander over part of the activities of subordinate or other organizations."* (JP 1) *"2. A tactical mission task that requires the commander to maintain physical influence over a specified area to prevent its use by an enemy or to create conditions necessary for successful friendly operations" (FM 3-90-1). "3. Physical or psychological pressures exerted with the intent to assure that an agent or group will respond as directed" (JP 3-0).*

These bullet points contain the most important references in ADP 1 to the importance of infrastructure. Two points (in bold type) explicitly call out infrastructure, the first for host nation infrastructure in support of local populations, and the second in support of friendly operations. Implied in all of these bullets are the capabilities to understand the nature of infrastructure and its relationship to mission accomplishment. The points also imply that specific actions are necessary to accomplish with respect to infrastructure.

While the significance of infrastructure to supporting landpower's five abilities is not directly described in ADP 1, it can certainly be inferred. First, destroying, preserving, or rebuilding infrastructures are potentially powerful actions to influence, shape, prevent, and deter potential allies and adversaries. Second, infrastructure is a key component of political and economic development. Third, restoring infrastructure and basic civil services is a necessary step to long-term recovery from catastrophic events (both natural and man-made events). Lastly, the availability of appropriate infrastructure is a critical requirement for joint forces to operate both inside and outside of the United States. Host nation infrastructure improvements are often required to ensure access for U.S. equipment and forces.

2.4.4 What the Army must do

The next section is "Our Roles: Prevent, Shape, and Win" (ADP 1, page 1-5) with a subsection for each term. The subsection for "Prevent" highlights that credible [U.S. Army] forces prevent conflict (ADP 1: page 1-5, para 1-11 and 1-12). Credible forces include the capability to fight when needed and the will to fight and win when necessary. There is a role of infrastructure to aid the role of "Prevent," but that role is not addressed in ADP 1.

The subsection, "Shape" includes an indirect reference to infrastructure in paragraphs 1-13 and 1-14. Shaping supports the efforts of the military and other "instruments of national power" – diplomatic, informational, and economic – to stabilize and strengthen partner nations. Shaping includes the need for military-to-military contact "and helping partners build capacity to defend themselves" (ADP 1, page 1-6). Capacity building normally includes improvements to the infrastructure in support of partner militaries and sometimes the host nation. Infrastructure improvements are often included in these improvement efforts.

Another indirect reference is found in the subsection "Win" (ADP 1: page 1-6 and 1-7, para 1-15 to 1-17). Paragraph 1-15 reminds the reader that "lethality, by itself, is not enough. If Army forces do not address the requirements of noncombatants in the joint operational area before, during, and after battle, then the tactical victories achieved by our firepower only lead to strategic failure and world condemnation." Typically, to "address the requirements of non-combatant" necessitates protecting infrastructure considered critical to the local population or rebuilding infrastructure that was destroyed or damaged by the conflict. What is implied in this paragraph is that winning the kinetic operations is not the objective of the operations but rather, the objective is defeating the enemy forces while terminating the drivers of conflict.[11]

The last section in Chapter 1 is "The Army Mission." For U.S military professionals, successful completion of the mission within the laws of the United States and other governing documents is the most important outcome (ADP 1). [12] On page 1-38, ADRP 1-02 defines "mission" as: [13]

> **mission –** (DOD) 1. The task, together with the purpose, that clearly indicates the action to be taken and the reason therefore. (JP 3-0) See ADP 5-0, ADRP 5-0, and FM 3-07.

Broadly stated, a mission is that which an organization (such as the Army or a tactical unit" or even a single individual must achieve within a given time, at a given location, and under a particular set of circumstances.[14]

[11] This concept is further developed in ADP 3-0 and other doctrinal publications.

[12] Page 2-7, para 2-20, Esprit de Corps: "Professionals exude purpose, demonstrate strong bonds of loyalty and pride, and place the mission above their own welfare." Page 2-9, para 2-25, Stewardship, "In practical terms, our public accounting as a profession occurs when the Nation calls us to accomplish the Army mission: to fight and win our Nation's wars." Page 3-6, para 3-18, Provide Flexible Mission Command, "All Soldiers prepare to place the mission first, take the initiative, and act resourcefully within their commander's intent." Page 4-1, para 4-1, Win the Current Fight, "Our immediate focus remains on accomplishing current missions." and "We remain mindful of their trust in us to get the mission accomplished in a way that brings credit to us and to the Nation." Page 4-7, para 4-18, Develop Army Leaders, "Mission success is realized through leaders who balance risk with the opportunity to retain the initiative".

[13] ADRP 5-0 repeats the definition and adds that "a mission statement contains the "who, what, when, where, and why of the operation."

14 An example of a combat mission might be for 1-5 Infantry (who: a particular unit) to attack by fire (what: to execute a particular type of tactical mission task) against enemy forces (a particular enemy) located at Objective Blue (where: a particular location) at 0400 local time (when: a specific time) to seize control and restore operation of the power station (why: a particular reason).

Despite this relatively straightforward definition, the "mission" is unique to the context in which it is applies.

The Army's mission is (ADP 1: page 1-8, para 1-21):

> The mission of the United States Army is to fight and win the Nation's wars through prompt and sustained land combat, as part of the joint force. We do this by—
>
> Organizing, equipping, and training Army forces for prompt and sustained combat incident to operations on land;
>
> Integrating our capabilities with those of the other Armed Services;
>
> Accomplishing all missions assigned by the President, Secretary of Defense, and combatant commanders;
>
> Remaining ready while preparing for the future.

While infrastructure is not directly referenced in the Army's mission, one of the key authorities for the Army does provide requirements that directly or indirectly reference infrastructure. The Army mission is derived from the intent of Congress, as codified in the laws governing the Armed Forces and other authorities established by the Secretary of Defense. Title 10, United States Code (U.S.C.) specifies congressional intent and requirements for the DoD and Services (ADP 1: page 1-8, para 1-18). Title 10 is refined and restated in Defense of Defense Directive (DoDD) 5100.01, "Functions of the Department of Defense and Its Major Components."[15]

This DoDD prescribes that the Army "shall develop concepts, doctrine, tactics, techniques, and procedures, and organize, train, equip, and provide forces with expeditionary and campaign qualities to perform the following specific functions (DoDD 5100.01, 28–29):

1. Conduct prompt and sustained combined arms combat operations on land in all environments and types of terrain, including complex urban environments, in order to defeat enemy ground forces, and seize, occupy, and defend land areas.

[15] This directive is signed by the Secretary of Defense.

2. Conduct air and missile defense to support joint campaigns and assist in achieving air superiority.
3. Conduct airborne and air assault, and amphibious operations. The Army has primary responsibility for the development of airborne doctrine, tactics, techniques, and equipment.
4. Conduct CAO. [Civil Affairs Operations]
5. Conduct riverine operations.
6. Occupy territories abroad and provide for the initial establishment of a military government pending transfer of this responsibility to other authority.
7. Interdict enemy sea, space, air power, and communications through operations on or from the land.
8. Provide logistics to joint operations and campaigns, including joint over-the-shore and intra-theater transport of time-sensitive, mission-critical personnel and materiel.
9. Provide support for space operations to enhance joint campaigns, in coordination with the other Military Services, Combatant Commands, and USG departments and agencies.
10. Conduct authorized civil works programs, to include projects for improvement of navigation, flood control, beach erosion control, and other water resource developments in the United States, its territories, and its possessions, and conduct other civil activities prescribed by law.
11. Provide intra-theater aeromedical evacuation.
12. Conduct reconnaissance, surveillance, and target acquisition.
13. Operate land lines of communication.

The majority of the 13 functions listed above are traditional combat responsibilities, but they also include civil affairs and civil works functions. In order to accomplish the combat functions, the Army will inevitably destroy infrastructure that enables enemy forces to operate. It is highly likely that this infrastructure also provides essential services for the civilian populations. Examples are utilities and transportation networks. Often civil infrastructure suffers from collateral damage in the course of operations by both friendly and enemy forces. Often infrastructure destroyed by kinetic operations must be rebuilt to support friendly operations. An example of this is the erection of temporary bridges to replace those destroyed to prevent movement of forces. The civil affairs and civil works functions include the preservation and expansion of existing infrastructure and the building of new infrastructure.

Chapter 2 of ADP 1 is titled “Our Profession.” It is primarily about what it means to be an Army professional. Under the section of “Military Expertise” is does recognize that the Army professional must have skills beyond traditional warfighting skills including political and cultural skills. These enable the Army professional to work effectively “*across and outside the Army’s institutional boundaries*” (ADP-1: page 2-4, para 2-9). These skills should include an appreciation for the role of infrastructure.

Chapter 3 of ADP 1 is “The Army and the Joint Force.” Because the joint force must operate “*in conjunction with the other instruments of national power—diplomatic, economic, and informational*,” the Army as part of the joint force must be able to do the same. Often the diplomacy includes the rebuilding or development of infrastructure and infrastructure is a key enabler of economic development. In the absence of other USG agencies (usually due to hostile conditions), the Army must be able to engage with local populations (ADP-1: page 3-1, para 3-1).

This section of ADP-1 also includes the eleven joint missions. Most of these missions have an infrastructure component, but five of the missions have large infrastructure components, as noted below:

1. *Project power despite anti-access/area denial challenges.*

Projecting power requires infrastructure to deploy and receive forces. The deploying forces are usually based on infrastructure on U.S. bases and installations or bases established on foreign soil by treaty or agreement with the host countries. Arriving forces normally will deploy to bases or facilities on foreign soil again, made available through treaty or agreement. Often, there is insufficient capacity for a large number of forces and improvements to host nation infrastructure is required. In cases where access is denied, existing facilities must be seized by force and often improved significantly (ADP-1: page 3-2, para 3-5).

2. *Defend the homeland and provide support to civil authorities.*

Defense of the homeland includes the protection of critical infrastructure and the restoring of infrastructure for U.S. civilian populations lost by natural or man-made events. Because the Army force normally operates in support of civil authorities, the Army relies on the civil authorities to provide actions to perform with respect to infrastructure.

3. *Provide a stabilizing presence.*
4. *Conduct stability and counterinsurgency operations.*

As mentioned in earlier sections of this chapter, stabilization operations require restoration and protection of host-nation infrastructure and basic services to local populations.

5. *Conduct humanitarian, disaster relief, and other operations.*

Humanitarian assistance (HA) and disaster relief (DR) operations are manpower intensive (ADP-1: page 3-2, para 3-5). This need is usually due to large-scale suffering and destruction of infrastructure, resulting in a loss of essential services. Often large-scale restoration of services is required in concert with other relief efforts by USG agencies, other countries, international organizations, and nongovernmental organizations (NGOs). Army capabilities are unique in their ability to provide significant resources (particularly logistics) in a relatively short period of time. Army defense of the homeland includes the protection of critical infrastructure and the restoration of infrastructure for U.S. civilian populations when infrastructure is lost by natural or man-made events. HA/DR operations differ from stability operations because HA and DR operate on a shorter time-scale and focus on immediate needs.

ADP 1, Chapter 3, also introduces "Core and Enabling Competencies." The core competencies are "combined arms maneuver" and "wide area security" (ADP-1: pages 3-3 and 3-4). Both of these competencies require attention to infrastructure, but for different reasons. Combined arms maneuver requires infrastructure to be "binned" as either a support for enemy capabilities or as a potential enabler for friendly operations. If infrastructure supports the enemy, it is often targeted for destruction. Destroyed infrastructure will likely require rebuilding, either to support friendly operations or to restore essential services of the friendly population. Careful consideration must be made by the planner on what options exist to deny or disable specific infrastructure benefits to the enemy. Less destruction will enable future, friendly operations in Phase 3,

"Dominate," and phase 4, "Stabilize."[16] If infrastructure can enable friendly operations, it may need to be seized and protected—ideally, intact.

Wide-area security requires the Army to "secure and control populations, resources, and terrain within the joint operational area" (ADP-1: page 3-4, para 3-14 and 3-15). This doctrine requires the Army to preserve and protect infrastructure within its operational area. Implied in this requirement is the repair or rebuilding of damaged infrastructure.

2.5 What doctrine says about assessments

For the Army as a whole, "assessment" is defined as "determination of the progress toward accomplishing a task, creating a condition, or achieving an objective" (ADRP 3-0 adopting the definition in JP 3-0). Clearly related to the more global joint definition of "assessment," assessments come in three types: initial, deliberate, and surveys. Each type of assessment serves as a precursor to the type that follows it, and each subsequent type becomes ever more particular in the information it seeks to capture. The ultimate goal of this increasingly fine-grained assessment process is to identify and mitigate "civil vulnerabilities that pose a threat to the successful and timely completion of the mission" (FM 3-57, para 4-18).

Initial assessments (also referred to in ATP 3-57.60 [*Civil Affairs Planning*] as "preliminary" assessments [e.g., para 3-8 and 4-45]) are conducted upon entry into a designated Area of Operations (AO); assessments are conducted to update the appreciation of the baseline conditions on the ground and to "validate or refute the information and assumptions used in planning as well as to update the CAO priorities and information collection plan" (FM 3-57, para 4-21). Doctrinally, an initial assessment has the following goals:

- Obtain a rapid overview of the conditions in the AO.
- Validate or refute information used during planning.
- Validate or refute assumptions used during planning.

[16] Other phases of operations: Phase 0 is "Shape," Phase 1 is "Deter," Phase 2 is "Seize the Initiative," and Phase 5 is "Enable Civil Authority."

- Determine general areas of perceived civil vulnerabilities.
- Update the CAO running estimate.
- Finalize or modify operations planned before deployment.
- Update CAO priorities.
- Identify key areas for follow-on deliberate assessments.
- Update the CAO information collection plan to provide input to the PIR and Commander's Critical Information Requirements (CCIR).
- Update the area study.
- Identify patterns and indicators.
- Identify requirements for follow-on Civil Affairs (CA) forces.
- Identify requirements for functional specialty support.

The contrast between an initial assessment and a subsequent deliberate assessment is dramatic, because a deliberate assessment is much more limited in scope and much more particular in the information it is constructed to obtain. Examples of the information-gathering tools that CA soldiers use in conducting deliberate assessments are first-hand observation, key-leader engagements, and interviews. Information is gathered by using these techniques with a view to enabling knowledgeable decisions and determining locations and priorities for a follow-on, in-depth analysis (FM 3-57, para 4-23). Doctrinally, the following are among the goals of a deliberate assessment (FM 3-57, para 4-24):

- Update the area study.
- Collect civil information on specific geographic areas (region, city, or town).
- Collect civil information on social, economic, governmental, legal, health, educational, or infrastructure systems.

- Determine specific areas of perceived civil vulnerabilities.
- Provide greater detail on priorities identified during the initial assessment.
- Update the CAO running estimate.
- Update the CAO information collection plan to provide input to PIR and CCIR.
- Identify key locations for follow-on surveys.
- Identify patterns and indicators.
- Identify key leaders for engagement.

The final and most-focused type of assessment that soldiers conduct is the survey. Surveys are carried out when the results of a deliberate assessment indicate that in-depth analysis is required, for example, of "specific people, groups, locations, facilities, or capabilities within a specific location or a specific piece within a system" (FM 3-57, para 4-25). The following are the objectives of such a survey (FM 3-57, para 4-26):

- Collect detailed civil information on specific location with a geographic area (e.g., forest, lake, valley, or neighborhood).
- Collect civil information on specific components of social, economic, governmental, legal, health, educational, or infrastructure systems (e.g., religious sect, water treatment plant, hospital, or prison).
- Identify capabilities and capacities, to include shortfalls, of surveyed items.
- Analyze specific areas of perceived civil vulnerabilities.
- Identify patterns and indicators.
- Identify possible project solutions to identified shortfalls and vulnerabilities when appropriate.

- Identify/verify key leaders.

2.5.1 Infrastructure planning within the doctrine

The next step is to investigate the ways in which the information that is gained is analyzed by using operational and mission variables. The Army planning process defines two types of variables: operational environment variables and mission variables (Table 2). Operational variables are "those aspects of an operational environment, both military and non-military, that may differ from one operational area to another and affect operations" (TRADOC Pam 525-3-0, "The U.S. Army Capstone Concept"). Study of operational variables in a particular location is begun before a specific mission has been assigned to a unit. Mission variables, on the other hand, provide prompts for a commander to develop specific plans once a unit receives a warning order or mission. Typically, some of the operational variables appear again in the mission variables, but these operational variables are filtered for relevance to the given mission. Each type of variable has its own methods to help planners, and some subset of each of these methods is relevant specifically to infrastructure assessment.

Table 2. The role of infrastructure in the Army planning process.

Variable type	Primary acronym to organize planning	Relevant variable for infrastructure	Infrastructure-specific acronyms
Operational	PMESII-PT	I for Infrastructure	SWEAT-MSO
Mission	METT-T**C**	C for Civil considerations	A**SC**OPE, where S is Structures and C is Capabilities (which in turn refers back to SWEAT-MSO)

PMESII-PT is the acronym that was developed for COIN operations in order to organize relevant information about the operational environment (FM 3-24.2, *Tactics in Counterinsurgency*). PMESII-PT recalls the eight operational variables: Political, Military, Economic, Social, Information, Infrastructure, Physical Environment, and Time. Users refine and update their understanding of these variables throughout the course of an operation (TRADOC Pam 525-3-0). Within the Infrastructure variable, the acronym SWEAT-MSO (Sewage, Water, Electricity, Academics, Trash–Medical, Safety, Other) is used to define the most critical infrastructure sectors. The SWEAT-MSO assessment methodology is explained in more detail in Section 2.5.1.1.

METT-TC is an acronym for the list of mission variables used to prompt Army leaders during the mission planning process: Mission, Enemy, Terrain and weather, Troops and support, Time, and Civil considerations (TRADOC Pam 525-3-0). Within the Civil considerations variable of METT-TC, the acronym ASCOPE for Areas, Structures, Capabilities, Organizations, People, and Events is further used to develop and continually refine an understanding of the mission variables (ATP 2-01.3, *Intelligence Preparation of the Battlefield*; ~~FM 2-01.3,~~ FM 3-24, *Insurgencies and Countering Insurgencies*) A matrix of ASCOPE and PMESII variables is shown in Table 3. Planners are instructed to develop, in conjunction with host-nation security forces and local government officials, both matrices and map overlays that detail these considerations in the operational area.

The *Structures* variable is the most directly relevant to physical infrastructure, but the *Capabilities* variable is also used to once again pull in the SWEAT-MSO variables. “Analyzing a structure involves determining how its location, functions, and capabilities support an operation. Commanders also consider the consequences of using a certain structure. Commanders must carefully weigh the expected military benefits against costs to the community that will have to be addressed in the future.” For each structure, the area and location associated with it should be identified, as well as its value from the perspectives of the population, the insurgents, and the counterinsurgents. Beginning at a minimum with SWEAT-MSO, locations associated with each ASCOPE capability must be identified (see Table 3). The individuals responsible for each capability, from the perspective of the population, insurgency, and counterinsurgency, must also be identified.

Table 3. Sample matrix of civil considerations (ASCOPE) and operational variables (PMESII) [Re-created from ATP 3-57.60, Table 4-1].
Note: See table footnote for abbreviation of spell outs used in table.

	P Political	M Military	E Economic	S Social	I Infrastructure	I Information
A Areas	District boundary, party affiliation areas	Coalition/ANSF bases, historic ambush/IED sites	Bazaar areas, livestock dealers, auto repair shops	Traditional picnic areas, bazaars, outdoor Shura sites	Irrigation networks, water tables, areas with medical services	Radio/TV/paper coverage areas, word of mouth gathering points
S Structures	Provincial/district centers, shura halls, polling sites	Provincial/District police HQ, INS known leader house/business	Bazaar, wheat storage, banks	Mosque, wedding halls, popular restaurants	Roads, bridges, electric lines, gabion walls, dams	Cell, radio, TV towers, print shops
C Capabilities	Dispute resolution, local leadership, INS ability to have impact	ANSF provides 24/7 security? QRF present? INS strength/weapons	Access to banks, ability to stand drought? Development	Strength of tribal/village traditional structures, Mullahs	Ability to build/maintain roads, walls, check dams, irrigation sys.	Literacy rate, availability of electronic media, phone service
O Organization	Political parties, INS group affiliation, gov. & NGO org.	Coalitions/ANSF present, INS groups present	Banks, large landholders, merchants, money lenders	Tribes, class, families, sport, shuras, youth shuras	Government ministries, construction companies	News organizations, influential mosques, INS IO groups
P People	Governors, councils, elder mullahs, parliamentarians	Coalition, ANSF, INS, military leaders	Bankers, landholders, merchants, money lenders	Mullahs, Maliks, elders, shura members, influential families	Builders, road contractors, local development councils	Media owners, Mullahs, Maliks, elders, heads of families
E Events	Elections, shuras, jirgas, provincial council meetings, speeches	Kinetic events, unit RIPs, loss of leadership operations	Drought, harvest, business openings, loss of business, good/bad crop	Friday prayers, holidays, weddings, deaths, births, bazaar days	Road/bridge construction, well digging, center/school construction	Friday prayers, publishing dates, IO campaigns, project openings, CIVCAS incidents

ANSF = Afghan National Security Force; CIVCAS = civilian casualty; HQ = headquarters; IED = improvised explosive device; INS = insurgents; IO = information operation; NGO = nongovernmental organization; QRF = Quick Reaction Force; RIP = relief in place.

Doctrine calls for the assessment models referred to above (from multiple points) but offers little further guidance on their use in analysis and planning. For example, FM 3-34 (*Engineer Operations,* p 3-9) provides doctrinal guidance for engineer reconnaissance for full-spectrum operations and describes the need for an engineering perspective on the basic infrastructure needed for a community or society: “The engineer view might identify challenges, to include environmental stewardship, financial and economic feasibility, social and cultural impacts, and the implications associated with specific deficiencies in the basic infrastructure and opportunities for improvement or development of the infrastructure.” However, the manual simply refers to using ASCOPE to

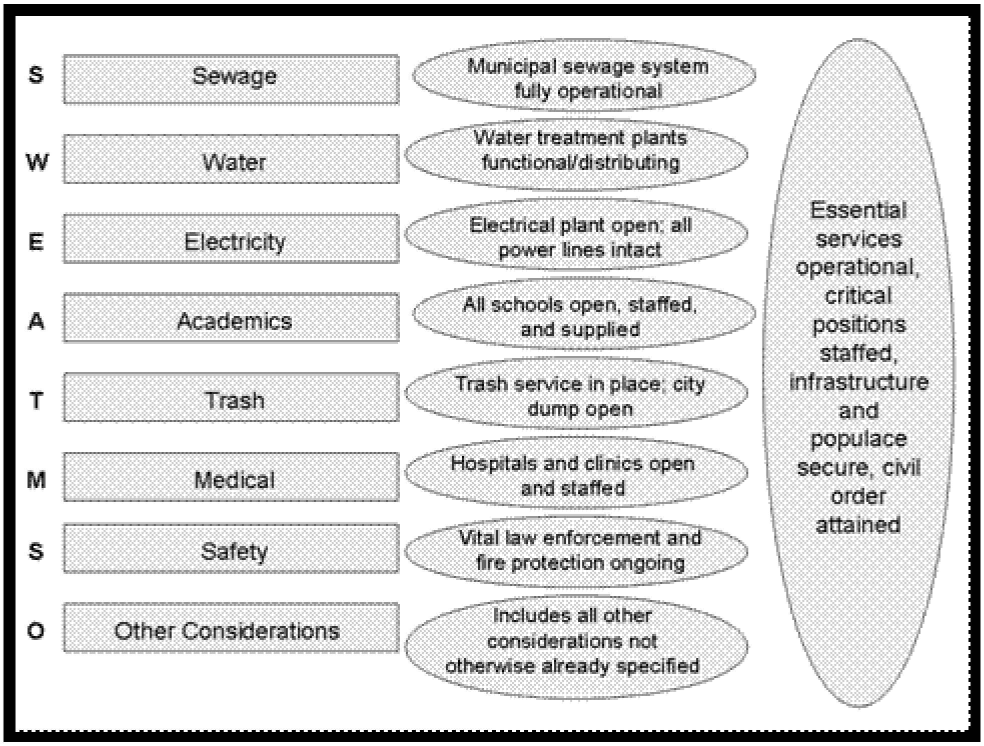
develop a “running estimate” maintained by the engineer staff to support decision making. A task assigned to an Engineer Warrant Officer to perform an IR survey simultaneously requires an assessment of social and cultural ASCOPE variables.

It appears that full development of both sets of operational and mission variables related to infrastructure, as guided by doctrine, would likely lead to redundant sets of maps and matrices. The use of matrices and sub-matrices may ensure that no major components are missed, and such matrices are therefore an important first step, but on their own they do not facilitate a holistic understanding of infrastructure systems. In practice, these methods provide units with nouns but not the back stories.

2.5.1.1 SWEAT-MSO (2005)

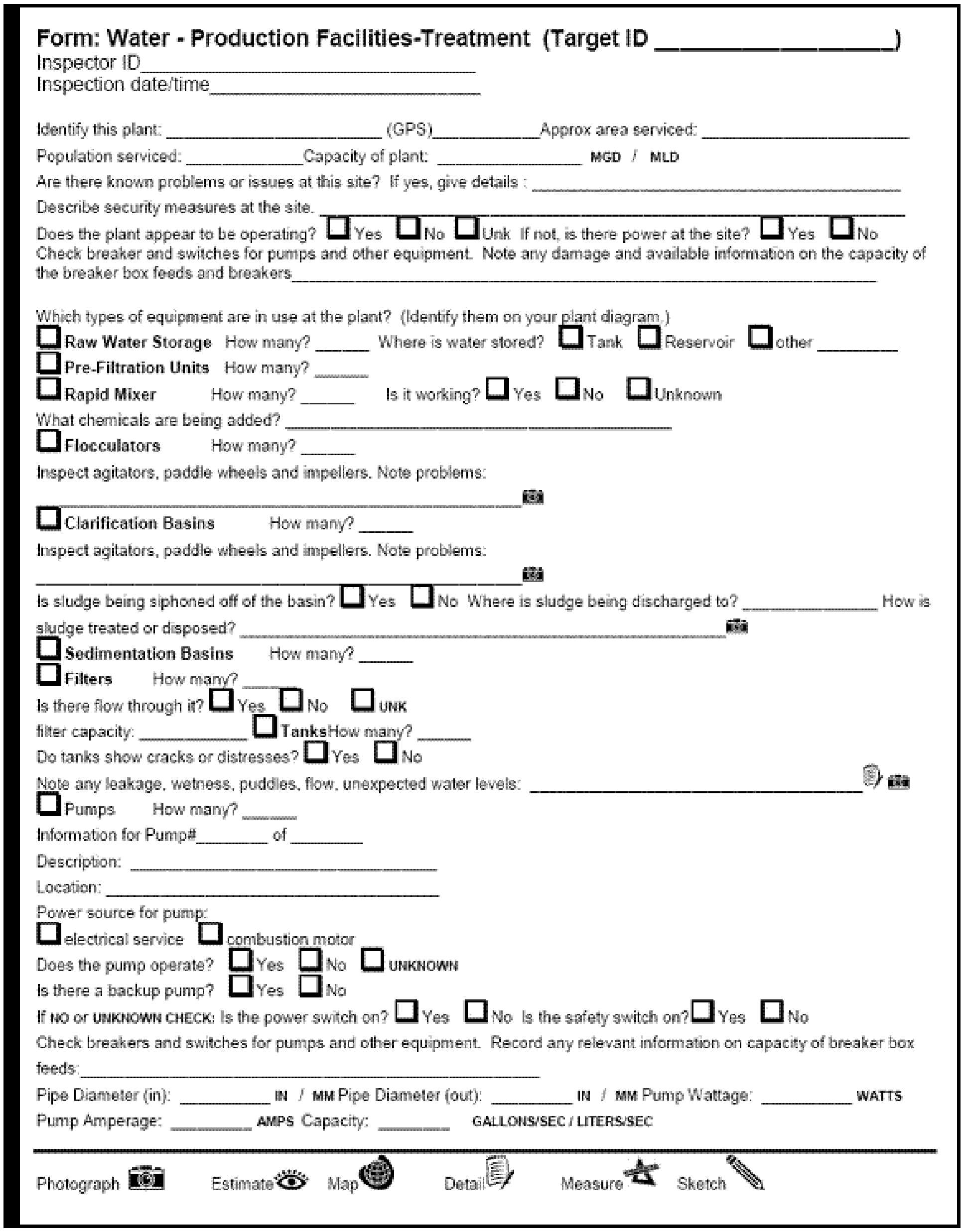
Because the SWEAT-MSO assessment methodology is used in both operational and mission planning variables, it is described in some detail here. It was designed to determine priorities and support the resolution of operational civilian infrastructure challenges, but it has also been used in attempts to set conditions for longer-term transition. The methodology identifies seven critical infrastructure sectors (Figure 4), as well as “Other Considerations” such as roads, railroads, bridges and waterways, airports, housing, communications, food supply, socio/government, cultural/historical/religious sites, and hazardous materials. Multiple versions of the SWEAT-MSO model have been developed over time, leading to some variation in the acronym and recommended assessment methods.

Figure 4. SWEAT-MSO critical infrastructure sectors (left side) (FM3-34.170, page C-1).



For each of the critical subsectors, forms for both a rapid initial assessment survey and "smartcards" for a somewhat more in-depth survey are provided in Appendix C of FM 3-34.170. The surveys focus on primary components, damage, maintenance, and provide guidance for further information collection such as the contact information of local operators. The smartcards are designed to help non-experts perform rapid surveys while at a specific site. They provide a list of specific questions and spaces for answers and checkboxes, and indicate that additional information should be attached. An example of the first page of a water treatment facility smartcard is provided as Figure 5.

Figure 5. First page of a SWEAT-MSO smartcard for a water treatment facility (FM3-34.170, C-7).



Form: Water - Production Facilities-Treatment (Target ID ________________)
Inspector ID___________________________
Inspection date/time______________________

Identify this plant: __________________ (GPS)__________Approx area serviced: __________________
Population serviced: ___________Capacity of plant: _____________ MGD / MLD
Are there known problems or issues at this site? If yes, give details : ________________________________
Describe security measures at the site. ____
Does the plant appear to be operating? ☐Yes ☐No ☐Unk If not, is there power at the site? ☐Yes ☐No
Check breaker and switches for pumps and other equipment. Note any damage and available information on the capacity of the breaker box feeds and breakers____

Which types of equipment are in use at the plant? (Identify them on your plant diagram.)
☐ **Raw Water Storage** How many? _____ Where is water stored? ☐Tank ☐Reservoir ☐other _______
☐ **Pre-Filtration Units** How many? _____
☐ **Rapid Mixer** How many? _____ Is it working? ☐Yes ☐No ☐Unknown
What chemicals are being added? __________________________________
☐ **Flocculators** How many? _____
Inspect agitators, paddle wheels and impellers. Note problems:
____
☐ **Clarification Basins** How many? _____
Inspect agitators, paddle wheels and impellers. Note problems:
____
Is sludge being siphoned off of the basin? ☐Yes ☐No Where is sludge being discharged to? ____________ How is sludge treated or disposed? ____
☐ **Sedimentation Basins** How many? _____
☐ **Filters** How many? _____
Is there flow through it? ☐Yes ☐No ☐UNK
filter capacity: __________ ☐**Tanks**How many? _____
Do tanks show cracks or distresses? ☐Yes ☐No
Note any leakage, wetness, puddles, flow, unexpected water levels: ___________________________
☐Pumps How many? _____
Information for Pump#_______ of _______
Description: ____________________________
Location: ______________________________
Power source for pump:
☐electrical service ☐combustion motor
Does the pump operate? ☐Yes ☐No ☐UNKNOWN
Is there a backup pump? ☐Yes ☐No
If NO or UNKNOWN CHECK: Is the power switch on? ☐Yes ☐No Is the safety switch on?☐Yes ☐No
Check breakers and switches for pumps and other equipment. Record any relevant information on capacity of breaker box feeds:____
Pipe Diameter (in): _________ IN / MM Pipe Diameter (out): ________ IN / MM Pump Wattage: _________ WATTS
Pump Amperage: ________ AMPS Capacity: ________ GALLONS/SEC / LITERS/SEC

Photograph Estimate Map Detail Measure Sketch

Some smartcards have a sociocultural focus. The socio/government smartcard consists of prompts for information about key leaders, government services, and businesses, while the cultural/historical/religious focuses on specific cultural sites. These cards were originally designed to assist combat engineers that may be the first ones to arrive at a site (FM3-34.170). These initial assessments would prioritize those infrastructure systems in need of more detailed surveys and assessments following the arrival of other engineer units such as Forward Engineer Support Teams (FESTs), and the authors acknowledged

that other non-engineers may need to be involved in or in charge of the assessments for some of the categories.

Moving beyond the smartcards, the Fm3-34.170 notes that an IR plan needs to be developed prior to the start of an operation and supported by a considerable amount of intelligence, some of which may become priority information requirements for a commander. These questions may include:

- Has the infrastructure been maintained?
- Who built that component of the infrastructure?
- Are repair parts/equipment available?
- Will the infrastructure be targeted by the host nation?
- Will host nation employees return to the site after hostilities?

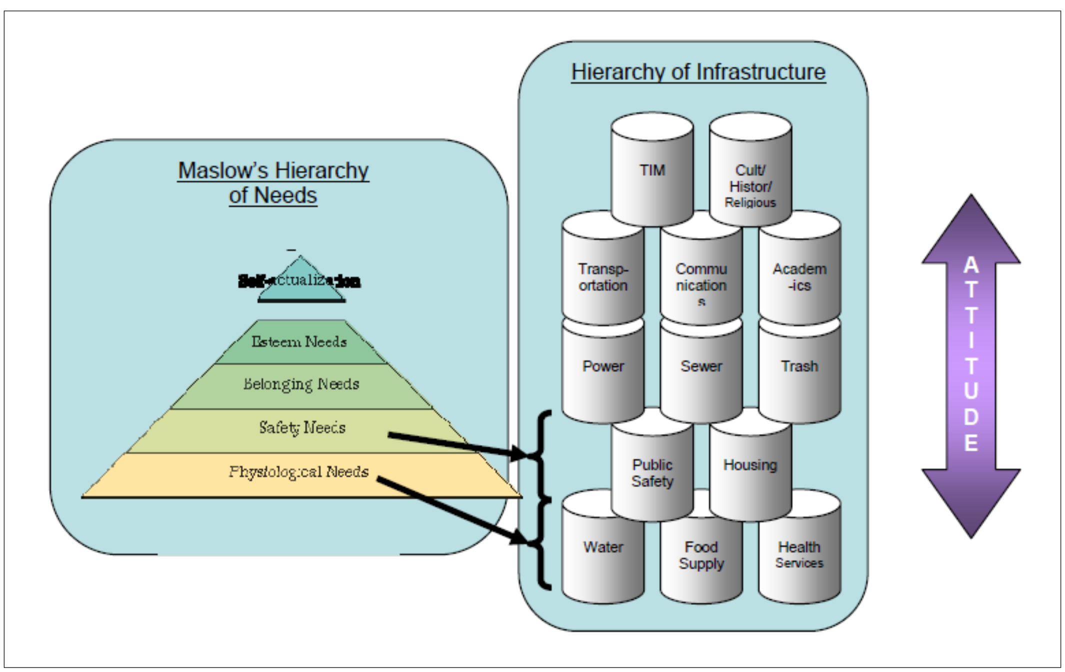
FM3-34.170 also supplies basic explanations, with diagrams and images, of the principal components of large infrastructure systems, as well as a list of useful tools (e.g. hammer, GPS, flashlight, tape measure). It reminds users that full inspection includes discussion with local users and operators to find intermittent problems not visible at the time of observation. This type of assessment presumes productive contact with operators is possible, because SWEAT methodology was not designed specifically for COIN or Anti-Armor Defense Data (A2D2) situations (Livingston 2011). Examples of the SWEAT rating methodology ranges are shown in Table 4, with green being 100 percent functional and black being destroyed.

Table 4. Examples of SWEAT black-red-amber-green rating methodology (re-created from USAES 2005).

Area	Green	Amber	Red	Black
Water	Water distribution works 100% of buildings	Water distribution works 50% strength, leaks	Water distribution does not work	No water distribution left, destroyed
	Tested as clean or told by locals clean	Appears clean, no smell	Does not appear clean	Contaminated water, smells
	Public facilities have running water 100%	Public facilities running water at least 50% buildings	Public facilities running water less than 50% buildings	Public facilities no running water
Sewer	Sewage system works, consistent	Sewage system runs but can't determine where/if treated	No treatment seen – something exists but broken	No sewage system left, destroyed
	No sewage seen or smelled	No sewage seen, can be smelled, damaged system	Sewage seen and smelled – system broken	Raw sewage and smell would be health issue
	Public facilities work 100% of buildings		Public facilities work less than 50% buildings	Public facilities no working sewer

The theoretical basis of infrastructure prioritization in the SWEAT methodology, indicated in the 2005 SWEAT Book (USAES 2005), is that infrastructure systems can be prioritized in parallel to Maslow's hierarchy of needs, and that a host nation's civilian attitudes also loosely correspond to the level of development of an infrastructure hierarchy that meets those needs (Figure 6).

Figure 6. SWEAT's theoretical basis for infrastructure prioritization (ERDC-CERL).



In addition to this hierarchy, the U.S. Military Academy (USMA) is cited within the book as having developed a list of considerations for operational prioritization of infrastructure that included the level of expertise and effort required for repair, the magnitude of health and safety impacts on the population, cost, local perception, impact of loss of functionality to local self-governance, and the degree of interdependency between a given item and other infrastructure activities.

2.6 What does it all mean?

All of the various categories of information expressed in the three cross-cutting schemata discussed here and their mnemonic acronyms (ASCOPE, PMESII-PT, SWEAT-MSO), are aimed at: (1) ensuring that needed information is gathered and in possession, and (2) allowing the development of not just situational awareness but also of situational understanding. The goal is the synthesis of a holistic, system-of-systems understanding of the operational environment (OE), to form an understanding that is shared by commander and staff and is used by both to support sound decision making.

The central goal of developing situational understanding is no less important in more recent articulations of CA doctrine than 2011's FM 3-57. For example, ATP 3-57.10 (*Civil Affairs Support to Populace and Resources Control*) asserts in para 2-2 that "[s]ituational understanding develops with detailed analysis of the operational and mission variables of the environment. A component of this analysis is population-centric." Newer doctrinal statements, however, articulate an even more subtle appreciation of the factors that need to be considered in the course of developing and maintaining that situational understanding. For example, the following statement describing the OE is indicative (ATP 3-57.10, para 2-3):

> The operational environment includes a wide variety of intangible factors such as the culture, perceptions, beliefs, and values of adversary, neutral, or friendly political and social systems. These factors must be analyzed and continuously assessed throughout the operations process to develop situational understanding of the environment.

The much richer understanding of the OE reflected in the ATP is a marked improvement over the definition (adopted from JP 3-0) in the Glossary to FM 3-57: "[a] composite of the conditions, circumstances, and influences

which affect the employment of capabilities and bear on the decisions of the commander" (FM 3-57, Glossary-9).

The challenges inherent in developing situational understanding are great, especially when (as in area studies, a process conducted remotely) there needs to be enough granularity and accuracy to be able to define the situation, to include relevant information in an operation order (OPORD) or similar product, to inform the consideration of potential courses of action (COAs), and to identify additional knowledge requirements. Accomplishing these goals involves gaining an understanding of the operationally relevant workings of the social and ecological systems presented to the analyst by the situation she is engaged with. The commander's intent for the operation has been defined, but the scope of its impacts, the risks of negative impacts, and the mitigation of potential negative effects still need to be analyzed carefully. The ability to carry out a meaningful COA analysis is predicated on achieving a reasonably accurate understanding of the systems on the ground.

Even having achieved a reasonably accurate understanding of the systems on the ground, other assessment-related challenges remain, among them the following:

- Shaping/influencing the outcomes of the intervention for mission success.

- Determining measures of effectiveness that express progress toward the desired outcome(s).

- Monitoring desired outcomes and integrating lessons learned into the planning of new operations.

3 Infrastructure Assessment Frameworks

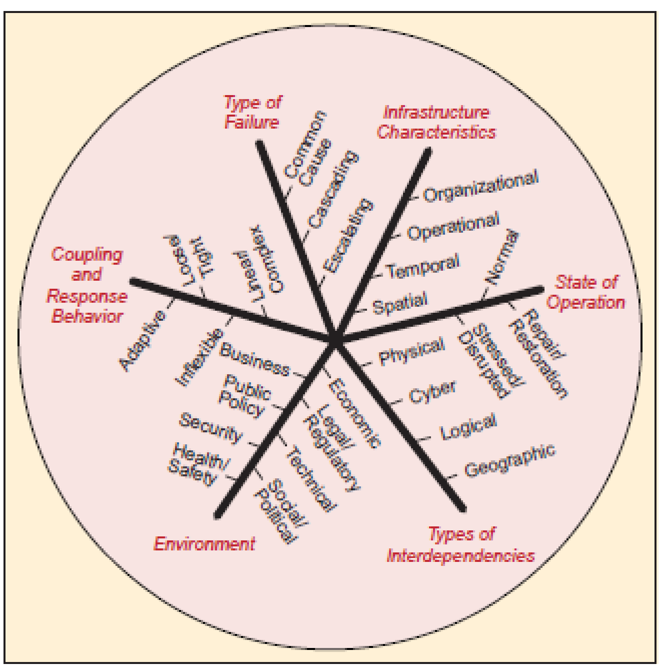
This chapter reviews a variety of methods, models, and tools for assessing infrastructure system characteristics. Beginning with a general examination of infrastructure planning and decision support models in section 3.1, the discussion moves on to section 3.2, which focuses on the development of interdependency computational methods that are encapsulated within the analytical planning and decision models.

3.1 Infrastructure planning

3.1.1 Rinaldi

Rinaldi et al. (2001) delineates six "dimensions" of an infrastructure's taxonomy to assist in understanding and analyzing infrastructure systems (dimensions are shown in red type in Figure 7). Of the six dimensions, a distinction is applied for the purposes of this report between three dimensions that can be applied to separate infrastructure subsystems and three dimensions that pertain specifically to infrastructure interdependencies, which are discussed in Section 3.2. The three dimensions most relevant to infrastructure assessment methodologies are: infrastructure characteristics, environment, and state of operations.

Figure 7. Each of the six dimensions for describing infrastructure systems and dependencies is shown by the words in red type (Rinaldi et al. 2001, 12).



As shown in Figure 7, Rinaldi (2001) places spatial scale, temporal scale, operational factors, and organizational factors within the first dimension, *infrastructure characteristics*. “Spatial scale” encompasses both geographic scale and, related to geographic scale, the level of granularity of an analysis wherein information requirements can span from the smallest part of an infrastructure unit to the scale of a massive, interdependent system. Infrastructure dynamics span a vast “temporal” range. Relevant time scales of interest vary from milliseconds to years. Rinaldi’s use of “operational factors” means aspects of how an infrastructure system is run when stressed or perturbed; such factors include operating procedures, operator training, backup systems, contingency plans, and enforcement. “Organizational factors,” similarly, can affect the ability to adapt to changing conditions.

The second dimension, *infrastructure environment*, “is the framework in which the owners and operators establish goals and objectives, construct value systems for defining and viewing their businesses, model and analyze their operations, and make decisions that affect infrastructure architectures and operations” (Rinaldi 2001, 16 [quoting Sage 1992]). This type of environment includes: economic and business opportunities and concerns, public policy including legal and regulatory concerns, government investment decisions, technical and security concerns, and social and political concerns.

The infrastructure dimension *state of operations* acknowledges that a given infrastructure system does not operate the same way in all circumstances. Normal operations typically encompass a variety of service demands such as peak and off-peak loads. Operations may proceed differently while repairs or upgrades are being made, and repairs may be planned or unplanned with consequent differences in operational states. Severe stress or disruption may also lead to different modes of operation, including the “mode” of complete failure of the infrastructure system. Each operational mode may require different inputs and produce different outputs.

Although the report’s authors are DoD-affiliated, the taxonomy they present is largely theoretical and is not fully present in existing military operational assessment methodologies.

3.1.2 U.S. Military Academy West Point, Department of Civil Engineering

Infrastructure can be viewed from multiple perspectives: as a target, an asset, and a weapon. "Destroying, or failing to protect, an infrastructure asset can impact political, social, and economic variables both immediately and for years into the future" (Hart et al. 2014, 17). To this end, West Point's Department of Civil Engineering has developed a suite of five infrastructure models as a tool to allow planners to think "critically, creatively, and completely" about infrastructure problems (Hart et al. 2014, 17). The models are intended to be applied in order, but they can be recursively applied as necessary. This suite of models has been tested to a limited extent, but it has not yet been applied operationally.

1. First, an *Environment* model serves to investigate the wider factors that shape the infrastructures in question. The eight subsections of this model are Needs that require infrastructure to be met, followed by considerations that are Social, Political, Technical, Financial, Organizational, External, and Enemy in nature.
2. The second model is the *Component* model, which uses the mnemonic "Grizzly Bears Don't Use Water Closets" to bring to mind the functions of <u>G</u>eneration, <u>B</u>ulk Transmission, <u>D</u>istribution, <u>U</u>se, <u>W</u>aste Management, and <u>C</u>oordination that are common to most infrastructure systems.
3. An *Assessment* model provides six prompts to guide a user through a status assessment of an infrastructure system, both under normal conditions and under adverse conditions.
4. Next, a *Development* model address the steps that need to be taken at both program and project levels to restore or develop essential infrastructure by using appropriate technology and establishing fundamentals that enable other agencies to move into an area.
5. Finally, a *Protection/Resilience* model borrows from the critical infrastructure literature, emphasizing actions that identify and defend hubs in the infrastructure network, work to repair links between them, or aim to survive disruptions.

3.1.3 Sand Book

The Sand Book (CCR 415-1) gives an example of a type of infrastructure assessment required by U.S. forces in basing situations. The whole document details standards for construction under Central Command

(CENTCOM). Annual assessments of each base are required. The assessment includes three-part Base Camp Master Plan (BCMP) that includes three different "phases" of development: Combined Air Operations Center (CAOC), Long-Range Development Component (LRDC), Short-Range Component (SRC). The assessments require narratives, maps, and answers to the direct survey-like questions. The document includes some interesting specifics on power assessment and design in host nations, where four construction phases (expeditionary, initial standard, temporary, sustained ops) correlate to four power-generation development planning phases. Weekly engineer situation reports are part of the requirements (including percentage complete and fund obligation date). The Sand Book provides an example of what the DoD requires in one existing, operational type of infrastructure assessment.

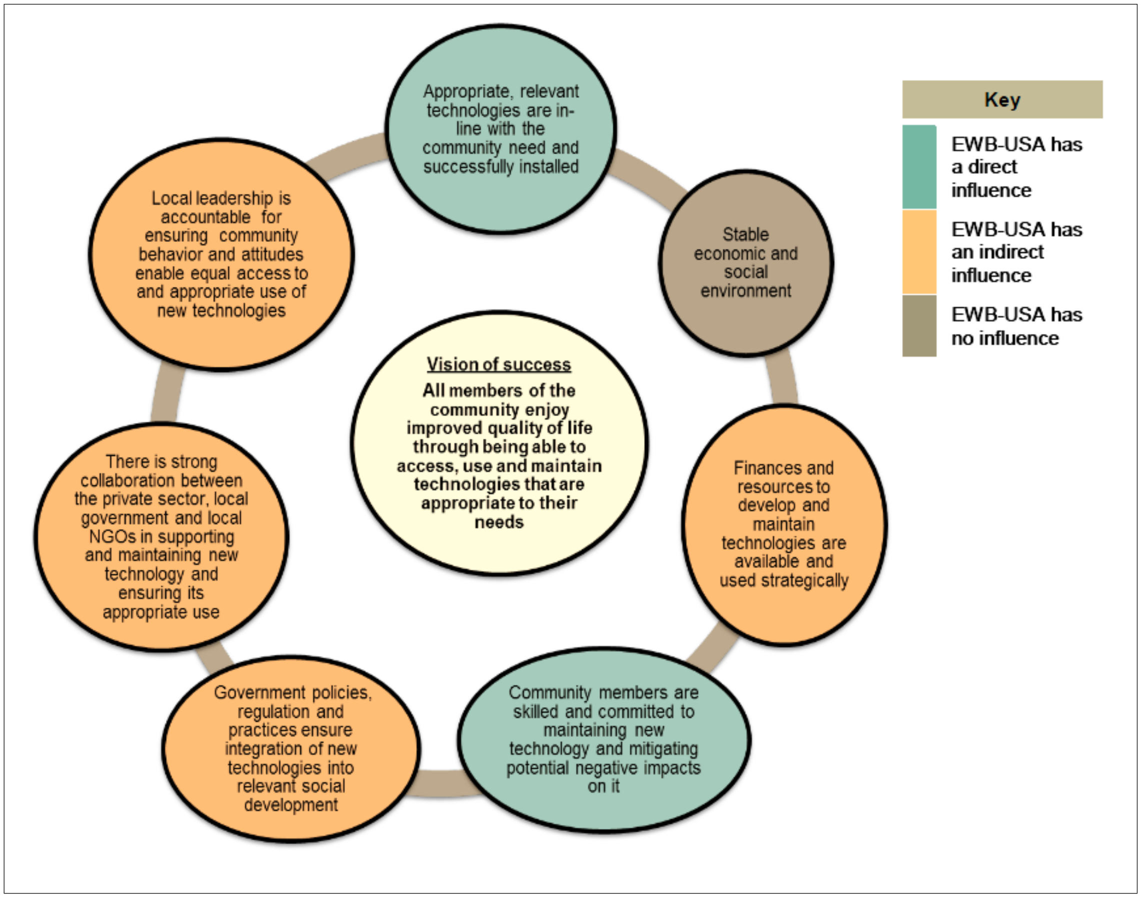
3.1.4 Engineers Without Borders

Engineers Without Borders (EWB) is an organization that provides technical expertise to community-led infrastructure projects. Projects must be brought to EWB by a local community organization and have the support, including some financial support, of either a local government or a local NGO. Figure 8 identifies seven key components to a successful EWB project, including the degree to which the organization has influence on each component; EWB only admits direct influence on two of the seven key components. EWB enables sustainability of engineering goals by placing decision-making power for the project in local hands; examples are holding elections for a village water committee charged with project maintenance or holding elections on the final project design. This bottom-up approach to building infrastructure avoids reliance on financial infusions into foreign systems.

Of note, EWB identifies four key questions about social structures that must be asked in the planning phases of a project:

1. Which different groups are included in this community?
2. What power structures exist? How might they help or hinder participation of all groups in the community?
3. How can we ensure that the views of all the different groups are/have been included?
4. How will we know that they have been included effectively?

Figure 8. EWB components of success and influences on them (EWB 2014, 7).



3.1.5 USAID/TCAPF

United States Agency for International Development (USAID) developed a Tactical Conflict Assessment and Planning Framework (TCAPF) to attempt to bridge the divide between shorter-term DoD combat operations and longer-term USAID development competencies. The framework highlights the importance of differentiating between needs, priority grievances, and sources of instability. For example, "in one case, locals cited water as a problem, but analysis identified the underlying source of instability as competition between two tribes over a well." Interventions must distinguish between needs, which can be great in less-developed countries, and actual sources of instability where a priority grievance directly undermines support for a just government or disrupts the normal functioning of society. The framework has four iterative phases: data collection, analysis, design, and evaluation, and relies on the ability to survey the local population.

3.1.6 World Bank

Following the 2008 financial crisis, the World Bank's Sustainable Development Network (SDN) aimed at enhancing the analytical tools to provide rapid infrastructure assessments created two tools to assess demand, supply, and risk/benefit screening of infrastructure programs and related financial support mechanisms in developing countries as part of the Infrastructure Recovery and Assets Platform (INFRA). These tools are focused on economic constraints, financial and investment needs, and institutional capacity, and thus the tools represent aspects of the infrastructure environment not specifically addressed by DoD infrastructure reconstruction efforts that typically have been paid for by U.S. funds. The two tools, which are lists of questions to be answered by the users, can be applied together or separately depending on the information needs of users; each tool is designed for use in three different modes: rapid, mid-level, and in-depth reviews (Figure 9). For example, the rapid review aims to use a small set of readily available variables to produce a global overview and developing country typology of infrastructure investment vulnerability (Figure 10), whereas the in-depth review would result in detailed modeling and impact evaluation and require significant expertise to complete (Figure 11).

3.1.6.1 Strategic Country Review

The first tool, the Strategic Country Review (SCR), provides a "top-down" perspective that is cross-sector and country-wide. It aims "to help address the question whether and how a country can effectively utilize a fiscal stimulus channeled through infrastructure investment to restore growth on a sustainable basis." The focus of this tool is the overall economic, financial, and institutional context for infrastructure investment. In particular, it evaluates the degree to which a country could absorb stimulus money for infrastructure that would (a) not perturb macroeconomic balances (e.g. not cause inflation), and (b) satisfy critical infrastructure needs that represent bottlenecks to development while generating sources of local employment and income. The tools include a list of questions and guidance together with templates that present key questions and variables and also indicate the extent of data availability and difficulty of data collection where unavailable.

Figure 9. Levels and uses of World Bank INFRA diagnostic tools (World Bank 2009, 5).

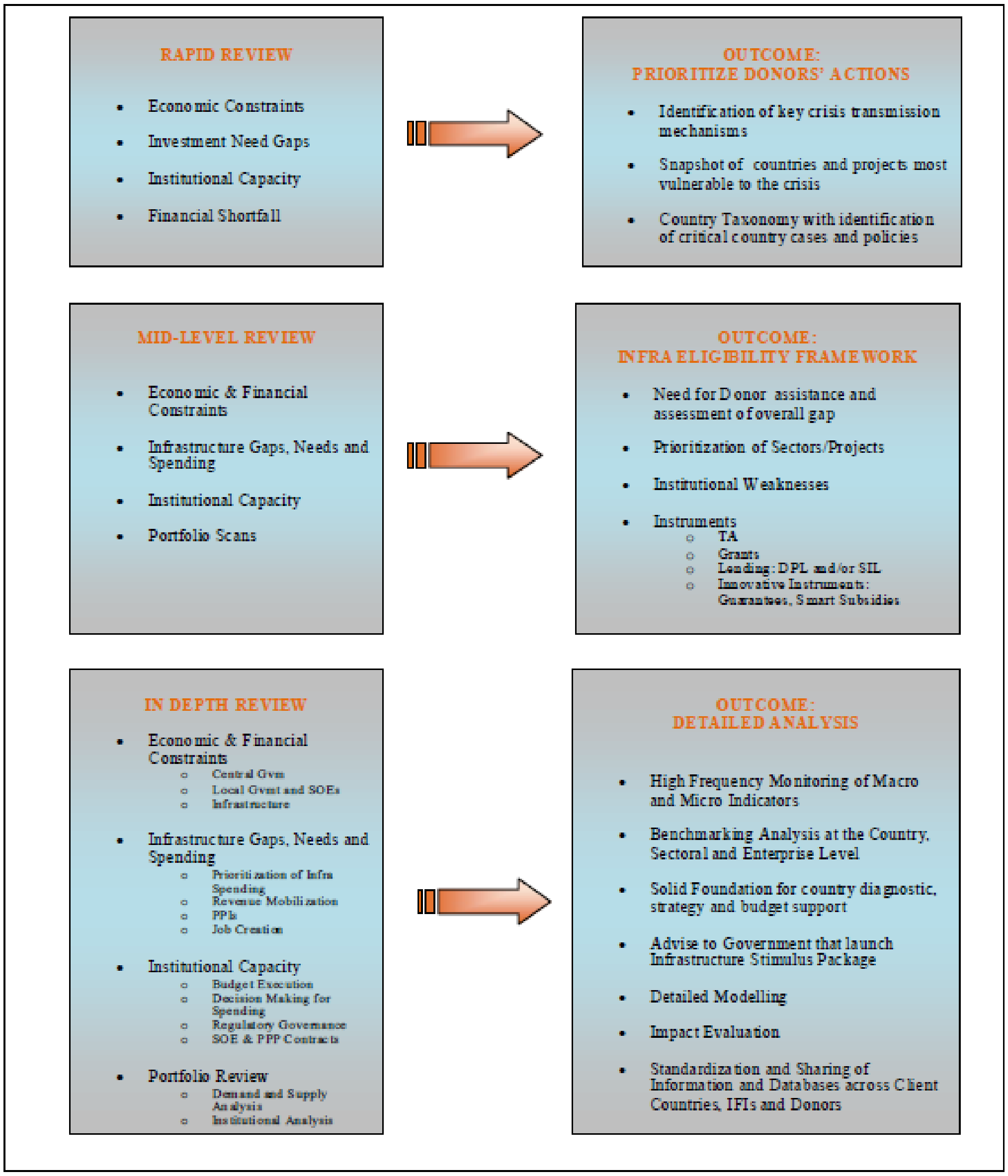


Figure 10. A preliminary developing-country typology of infrastructure investment vulnerability (World Bank 2009, 13).

Table 2
Investment Need Gaps and Fiscal Space

Fiscal Space The higher the fiscal space the greater the ability to undertake a fiscal stimulus program and finance such a program by taking on additional debt without unduly jeopardizing the sustainability of its macroeconomic balances	Investment Need Gaps The higher the investment needs the greater the infrastructure investment gaps as a percentage of GDP **Low**	**Medium**	**High**
Low	Congo, Dem. Rep. Croatia Lao PDR Latvia Mauritania Sudan Uruguay	Albania Brazil Côte d'Ivoire Djibouti Ethiopia Ghana Madagascar **Poland*** Sri Lanka Turkey	Argentina Burundi Egypt Gambia Georgia Guinea Guinea-Bissau India Jamaica Jordan Kyrgyz Rep. Liberia Malawi **Mauritius*** Mozambique Nicaragua Pakistan Panama Senegal Tajikistan Togo
Moderate	Bangladesh Cambodia Comoros Dominican Rep. Indonesia Kenya Mali Mongolia Niger Philippines Vietnam	Burkina Faso Central African Rep. Haiti Kazakhstan **Mexico*** Nepal **Romania*** Rwanda Yemen Zambia	Armenia Belarus Benin **Bulgaria*** Colombia Costa Rica El Salvador Guatemala **South Africa*** Tanzania Tunisia Uganda Ukraine Honduras Morocco
High	Angola Botswana Chad China Gabon Malaysia Nigeria Papua NG Thailand	Algeria Azerbaijan Cameroon Peru Russian Fed. Sierra Leone Turkmenistan Venezuela	Bolivia Chile Ecuador Iran Lesotho Paraguay Swaziland Uzbekistan

Source: preliminary own elaboration

Note: The country ranking of fiscal space is reported in World Bank 2009 (c).
The country ranking of investment needs gap is based on the revised infrastructure needs estimated by the authors, based on Fay and Yepes (2003) and Yepes (2008) for 2008-2015 compared to the pre-crisis baseline.[5]

Figure 11. Examples of methodologies to assess infrastructure investment needs (World Bank 2009, 12).

"Benchmarking"	Set target
Examples: ❖ **Stock target**: what would it cost to get a given country's infrastructure (per capita; per unit of GDP; per km2) to the level of the Regional leader; or to the level of another region median? ❖ **Flow target**: how does a given country's expenditures on infrastructure compare to peers.	**Examples:** ❖ **MDGs** - what would it cost for a given country to achieve universal service coverage in water and sanitation, electricity and access to all year round roads. ❖ **National Targets** – what would it cost for a given country to achieve targets under their national plans2?
Econometric: ❖ **Growth:** What level of infrastructure coverage is needed to achieve x% level of growth and reduce inequality by z%. This is the approach followed by Calderón and Servén (2004) applied by Estache (2005) in the case of Africa. ❖ **Demand**: What level of infrastructure coverage will be demanded by firms and consumers, for given growth projections. This is the approach followed in Fay and Yepes, 2003 and extended by Bogetić and Fedderke (2006) in the case of Africa.	**Micro sectoral estimates:** These can be economic-engineering models that price particular level of coverage and quality; or it can be more ad-hoc, relying on sector data and expert opinions. - **Power sector:** *well defined international methodology, used by electricity companies to estimate investment needed to maintain the integrity of the network and satisfy predicted expansion in demand.* - *Roads: well defined methodology for rehabilitation/maintenance expenditures; combined with road sector expert opinion on definition of major corridors and investment needs for their completion.*

3.1.6.2 Infrastructure Portfolio Assessment Review

The second tool, the Infrastructure Portfolio Assessment Review (IPAR), provides a "bottom-up" perspective that provides a sector-by-sector review of existing infrastructure project portfolios. The purpose of this review is: (a) to understand the specific impacts the financial crisis is having on existing infrastructure projects and (b) to evaluate how current infrastructure investment pathways line up with economic and social goals for that country. The full IPAR includes four components: (1) infrastructure needs and demands in specific subsectors, (2) economic and technical aspects of supply (project portfolio, degree of completion, strategic importance, risks and benefits), (3) institutional capacity (the ability of private and public actors to use money appropriately and provide incentives via regulation), and (4) government capacity to implement and monitor policies.

The infrastructure sectors covered by this World Bank tool are:

- transport (including ports, roads, and freight subsectors),
- energy (with generation, transmission, and distribution subsectors),

- water (with subsectors in upstream water resources management, irrigated agriculture, irrigation drainage, urban and rural water supply and sanitation),
- urban (urban infrastructure, slum upgrading, affordable housing, and maintenance of urban infrastructure), and
- telecommunications (with three subsectors in international connectivity, backbone domestic transmission, and local access networks).

The main sources of information for the IPAR typically include: sectorial ministries, regulatory agencies, service administrators, main operators, investment promotion agencies, regional and local government agencies, business organizations, and banks. The tool provides specific, sector-by-sector questions to be answered in an in-depth analysis. A synthesis of the analysis is then suggested by a red-amber-green matrix that rates implementation ease and strategic importance of both infrastructure projects and financial policy opportunities.

3.1.7 Standards organizations

Several bodies develop geospatial standards relevant to infrastructure assessments such as Technical Committee #211 of the International Organization for Standardization (ISO/TC211), the Defense Geospatial Information Working Group (DGIWG), and the Open Geospatial Consortium (OGC). When feasible, it is advisable to use pre-existing, standardized formats for organizing infrastructure information to allow information to be shared more easily between applications. Two examples of these systems of organization are described below.

The National System for Geospatial-Intelligence (NSG) Application Schema v5.0[17] uses content from the NSG Entity Catalog and structure from ISO/TC211 19100-series standards. As an example, several properties are associated with the entity name “Electric Power Station”: geometry, directivity (indicating whether its visibility tends to be directional), generation capacity and units, power source (e.g., geothermal,

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[17] Web link for the NSG working group responsible for the Schema: http://www.gwg.nga.mil/index.php.

hydroelectric, nuclear, thermal, tidal), raw material (e.g., coal, gas, liquefied natural gas), and associated units (e.g., cooling towers, power generating units, smokestacks, cables). Each entity is then connected through classes and groups. For example, the Electric Power Station is in the Cultural group, indicating that it is human-constructed. The Cultural group is then classified into Power Generation and Transmission Facilities. It is also a subclass of Facility, under which other attributes are stored such as Controlling Authority (e.g., civilian, military, private, public), Facility Operational Status (e.g., continuous, intermittent, nonoperational), Historic Significance, Physical Condition, and whether it is a member of a Facility Collection, among others. The schema provides very specific guidelines as to how these attributes are to be specified.

The DGIWG Feature Data Dictionary Baseline 2101-2.00[18] is an ISO-compliant feature attribute data registry that specifies feature concepts, groups, subgroups, attribute characteristics, data types, physical quantities, and units. For example, the feature concept Electric Power Station belongs to the Industry and Services group, and to the Power Supplies and Associated Support Structures subgroups. Links are provided to a current version of the data dictionary online, and any changes over time can be viewed. This data dictionary provides a standard structure for organization of entities but, unlike the NSG Application Schema, it does not attempt to specify all required attribute fields.

3.1.8 Department of Homeland Security

The DHS provides an Automated Critical Asset Management System (ACAMS) designed to help U.S. police, public safety, and emergency response units collect infrastructure data, assess vulnerabilities, and develop response and recovery plans. Access to this system is limited to trained state and local responders. The National Critical Infrastructure Prioritization Program (NCIPP) identifies and prioritizes critical infrastructure and allows users to assess risks (threats, vulnerabilities, and consequences) to that infrastructure. The program does not mandate certain risk assessment methodologies but requires them to be documented, reproducible, and defensible.

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[18] Web link to the DGIWG: https://www.dgiwg.org/dgiwg/htm/about_DGIWG/about_dgiwg.htm

3.1.9 Department of State Maturity Model

In Iraq, Provincial Reconstruction Teams produced quarterly assessments of project development based on a Department of State Maturity Model. The model does not address infrastructure directly, but it is geared toward assessing governance surrounding infrastructure and other projects including contract administration, independent government functioning, and the potential for further development (USAID, 2014)

3.2 Infrastructure interdependency and modeling

Because an understanding of infrastructure interdependencies is critical to a full infrastructure assessment, this section presents existing operational and theoretical methods of assessing infrastructure interdependencies. Some of these methods are very physically-focused, where the interdependent systems of interest are other physical infrastructure sectors, and many are focused on DHS applications and/or natural hazards. Other methods recognize that analysis of interdependent systems should include larger systems such as governance and finance, and are part of larger social systems; these methods appear to be largely theoretical.

3.2.1 Rinaldi

Rinaldi et al. (2001, 14) define a *dependency* as “a linkage or connection between two infrastructures, through which the state of one infrastructure influences or is correlated to the state of another.” According to this definition, an *interdependency* describes a bidirectional link or connection such that one infrastructure depends on a second infrastructure through a certain set of links, while the second infrastructure also depends on the first via another set of links (Rinaldi et al. 2001, 14). An example of such interdependency is the reliance of a coal-fired power station on rail transportation to deliver coal, while the railroad also relies on power for signaling; therefore if an electric outage occurs, there is potential for compounded electrical failure if the railroad cannot deliver coal to power stations on schedule. Rinaldi uses the term “interdependency” broadly in order to be inclusive and encourage a thorough and systematic approach, but almost all aspects of the six dimensions can be used to describe one-way dependencies as well as bi-directional or multi-directional interdependencies.

Rinaldi delineates six “dimensions” of infrastructure taxonomy to assist in understanding and analysis of infrastructure systems. These dimensions do not represent “a comprehensive set of orthogonal interdependency metrics,” as components of these dimensions may overlap to create interdependencies. Three of the six dimensions focus on interdependencies and are described in more detail on the pages that follow: types of interdependencies, coupling/response behaviors, and types of failures.

3.2.1.1 Types of interdependencies

Rinaldi (2001) defines four types or classes of interdependencies: physical, cyber, geographic, and logical; these categories are explored in more detail in Brown (2008) but are explained briefly here. A *physical interdependency* occurs when an input to one infrastructure depends on the material output of another. A *cyber interdependency* occurs if the state of an infrastructure system depends on signals transmitted via information infrastructure (Figure 12). A *geographic interdependency* occurs when a local environment can create state changes in multiple infrastructure systems; this typically occurs due to some combination of geographic proximity of the infrastructure systems and the spatial extent of an external perturbation event such as a fire or hurricane. The term *logical interdependency* is used for all other dependency mechanisms, notably economic and financial mechanisms that affect infrastructure or commodity supply and demand and other processes that feature human decision making.

Coupling and response behaviors between infrastructures constitute another interdependency dimension. A tight coupling is an interdependency in which processes are highly time-dependent, and where there is little local storage in the system and therefore disturbances propagate rapidly, whereas a coupling with sufficient temporal flexibility and/or local storage may exhibit a time lag or dampened effects after a perturbation and is considered loosely coupled. Coupling order describes the direction and order of dependencies, and may include second-, third-, and higher-order effects. Rinaldi et al. (2001) briefly and informally discuss notions of linear versus complex behavior before discussion of the characteristics of adaptability or inflexibility under stress or perturbation. Adaptability is enhanced by availability of substitutes for critical parts and processes, contingency plans, backup systems, operator training, and simple ingenuity in times of need. Inflexibility is increased by legal and

regulatory requirements borne of past or present health, safety, social, and organizational concerns, as well as by the limitations of existing infrastructure and the high cost of improvements and backup systems. Figure 13 shows an example of how infrastructure systems can be classified according to interdependency characteristics.

Figure 12. Some physical and cyber infrastructure interdependencies (Rinaldi et al. 2001, 15).

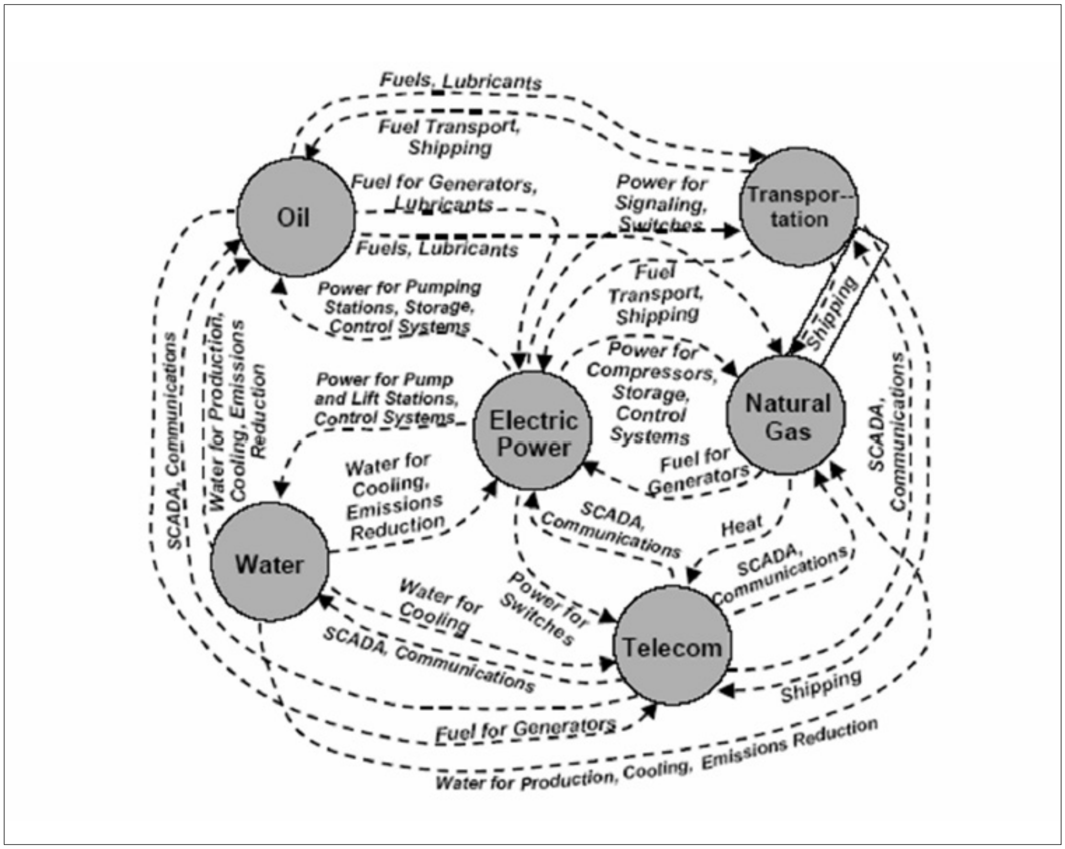
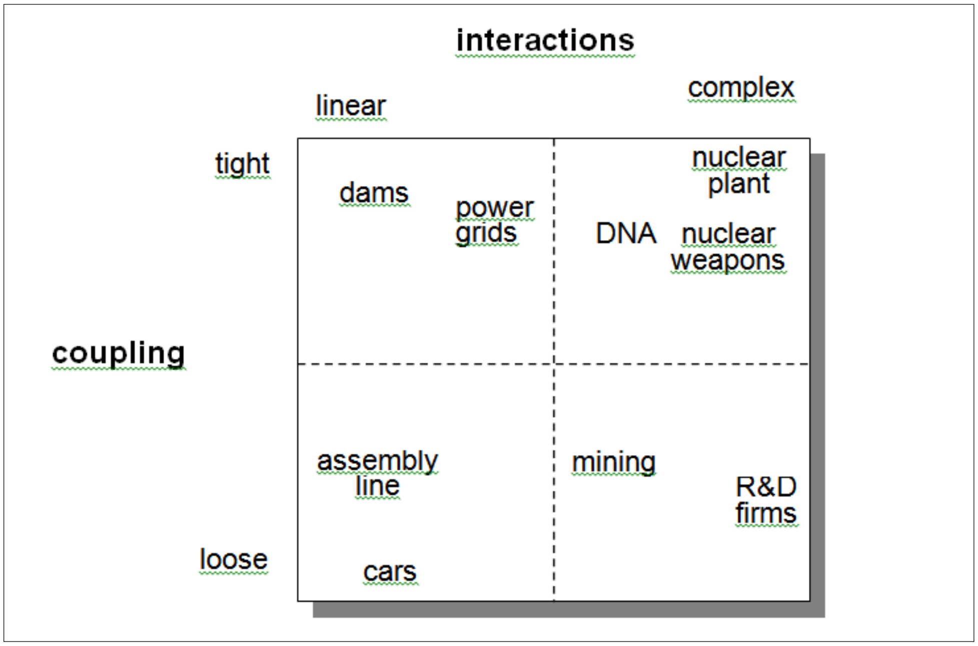


Figure 13. Perrow's classification of systems by interaction types (Perrow 1984, 2).



Rinaldi et al. identify three types of failure due to interdependencies: cascading, escalating, and common cause. A *cascading failure* is the typical interdependent failure where an outage in one system directly causes an outage in a dependent system. An *escalating failure* does not directly cause failure in a dependent system, but rather it weakens the ability of the dependent system to recover from any simultaneous but independent failure. *Common cause* refers to the situation where failures are correlated due to geographic area or some widespread affect, but are not directly causally connected to each other.

According to Rinaldi et al., infrastructure systems can be viewed and potentially modeled as complex adaptive systems (CASs). A CAS consists of interacting parts whose behavior and components can change as the result of some type of evolution or learning process. The term "emergent behaviors" is used to describe "macroscale" features which arise from a complex networked system, often without planned central control, but are not directly attributable to or fully controllable by any single subsystem. One mode of investigating the behavior of CASs is agent-based modeling, whereby a set of agents (entities with locations, sets of capabilities, and memories) communicate, passing inputs and outputs to other agents, each of which can potentially affect the location, capabilities, and memories of other agents (Rinaldi et al. 2001, 13). This type of modeling allows for

exploration of a complicated system when the rules that affect individual agents are reasonably well-constrained.

3.2.2 SWEAT book

In contrast to the multidimensional approach to interdependencies taken by Rinaldi et al., operational consideration of interdependencies is limited. The SWEAT Book acknowledges that infrastructure categories are not closed systems, and identifies potential links between infrastructure categories (Figure 14). It states that a staff/commander must be aware of these links before altering them in a significant manner (USAES 2005). Apart from this, no specific guidance for dealing with infrastructure dependencies is provided.

Figure 14. Links between Infrastructure reconnaissance categories (USAES 2005).

Under Development

	Food Supply	Water	Health Services	Public Safety	Housing	Socio-Economic	Power	Sewer	Trash	Transportation	Communications	Academics	TIM	Cult/His/Religi.
Food Supply		X		X	X	X	X			X		X		
Water	X		X	X	X		X	X				X		
Health Services		X		X			X		X		X			
Public Safety	X	X	X		X	X	X	X		X	X	X	X	X
Housing	X	X		X		X	X	X	X	X		X	X	X
Socio- Economic	X			X	X		X			X	X	X	X	
Power	X	X	X	X	X	X		X		X	X	X	X	
Sewer		X		X	X		X			X		X		
Trash			X		X					X		X		
Transportation	X			X	X	X	X	X	X			X	X	X
Communications			X	X		X	X							
Academics	X	X		X	X	X	X	X	X	X				
TIM				X	X	X	X			X				
Cult/Hist/Relig.				X	X					X				

3.2.3 Argonne National Laboratory

Core capabilities at Argonne National Laboratory (ANL) include systems analysis, modeling, simulation and visualization, complex adaptive systems, and decision support and risk management. Of particular note, ANL is designing a TRADOC-funded Infrastructure and Essential Services

Economics (IESE) model that aims to link community perceptions, tasks, social networks, and microeconomics to infrastructure and essential services. Software representations are shown in Figure 15, Figure 16, and Figure 17, and the end product was designed to be part of an Irregular Warfare Tactical War Game simulation suite as well as a stand-alone application. Key design elements for IESE, in priority order, were (Verner and Petit 2014):

1. Representation of the active role of communities in shaping and framing a population's perceptions and beliefs regarding the adequacy of infrastructure and delivery of essential services.
2. Representation of the multiple roles played by social networks in channeling and modulating societal activities related to infrastructure and essential services.
3. Representation of classical microeconomics themes such as commodity supply and demand, prices, and employment, within the context of infrastructure development and maintenance and delivery of essential services.
4. Representation of task networks (supply chains, etc.) to model the interlinked social and physical dynamics of infrastructure and essential services processes.
5. Support for the integration within the IESE simulations of physics-based models to explicitly represent such key processes as infrastructure system performance (electrical grids, water and sewer systems, etc.) and evolution over time of natural processes, such as those associated with agriculture, that are intimately interlinked with the social mechanisms of IESE.

Figure 15. Simplified IESE software representation of interlinked physical and network elements (Verner and Petit 2014, 3).

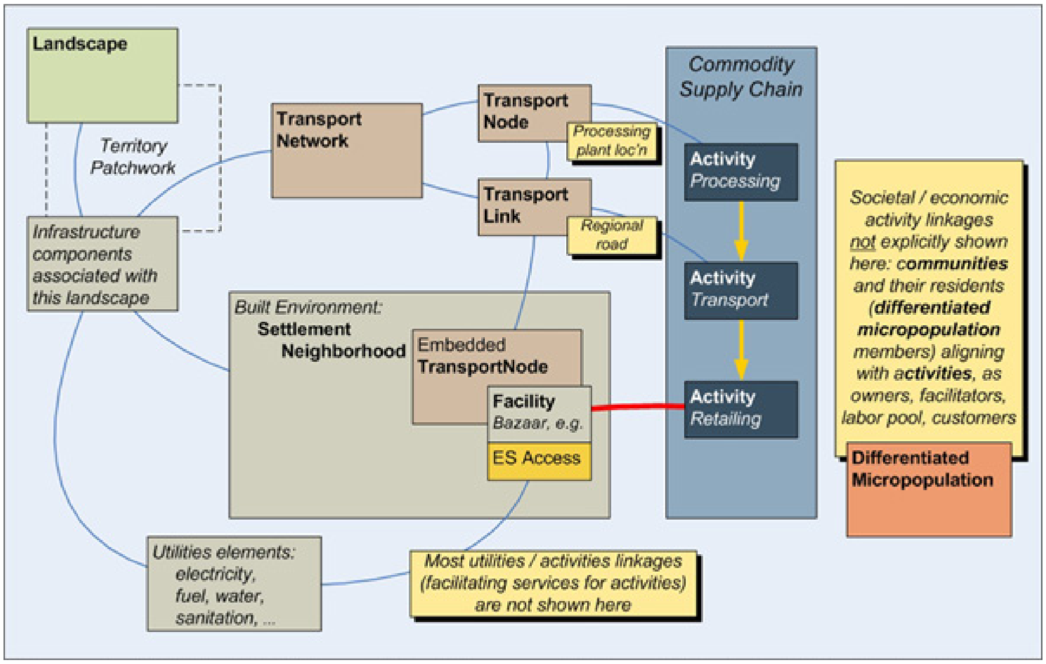


Figure 16. IESE economics example: access to food (Verner and Petit 2014, 5).

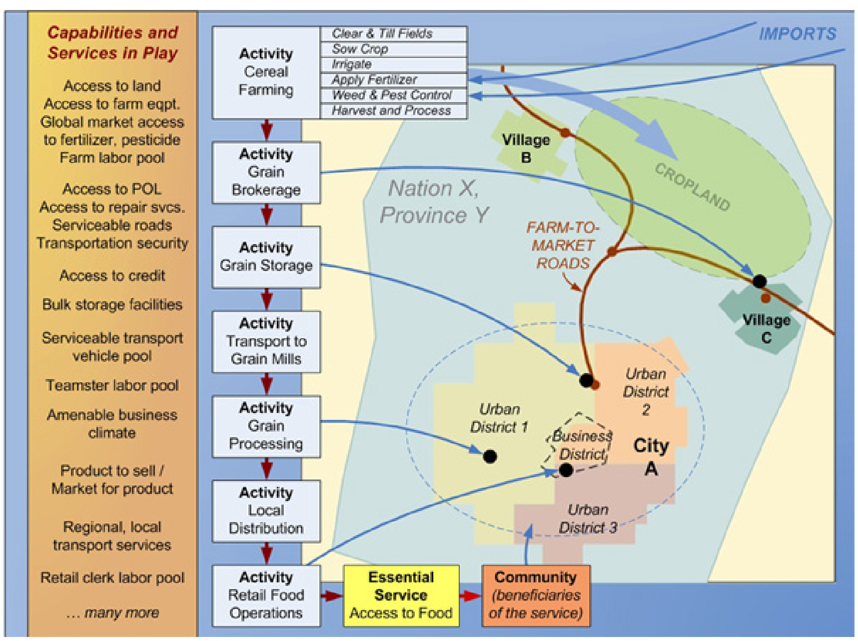
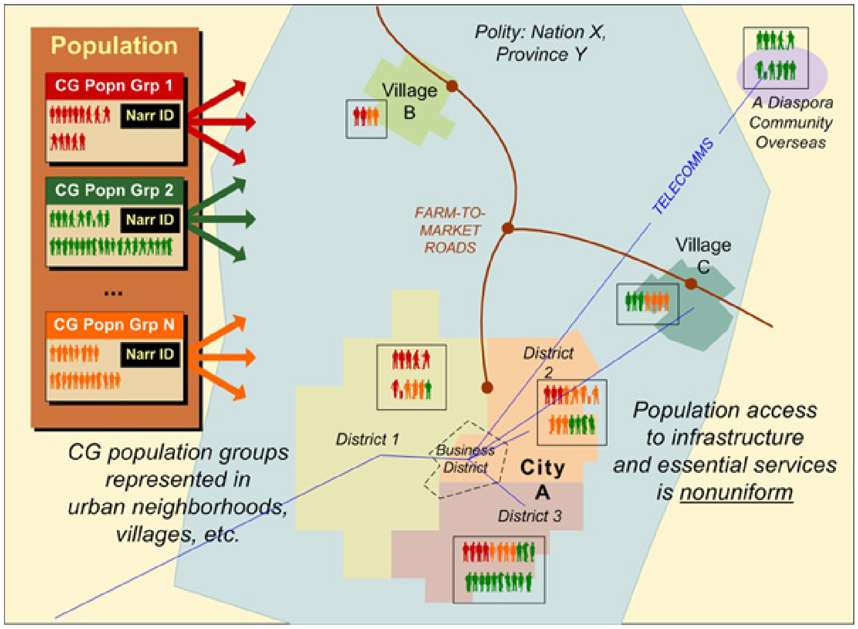


Figure 17. Mock-up of population group distribution view (Verner and Petit 2014, 5).

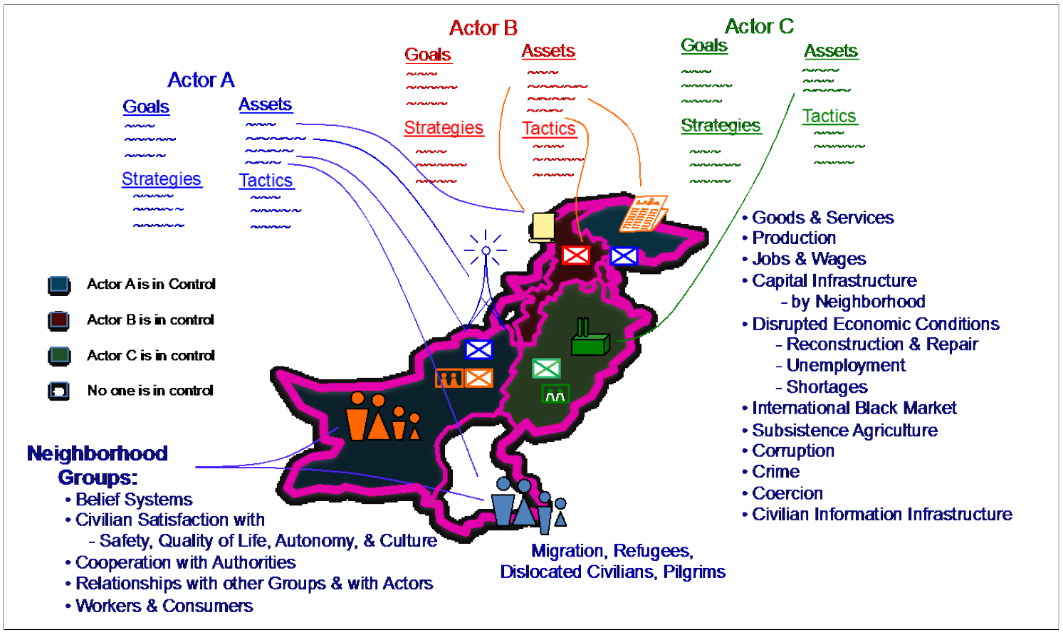


3.2.4 The Athena Project

The Athena Project aims to provide a computable general equilibrium model (CGEM) to help analyze operations that involve multiple elements of national power: diplomatic, informational, military, economic, financial, intelligence, and law enforcement (Chamberlain, Duquette and Kahovee 2012). The user simulates an environment where actors have goals, assets, strategies, and tactics that are executed on a weekly basis. The user defines communications and manufacturing infrastructures and specifies initial economic and attitudinal conditions. Simulations can increment in weekly time steps to analyze medium-term planning horizons (3 months to 3 years). Multiple social and cultural attributes such as cooperation, satisfaction, and inter-group relationships are modeled numerically, with the option to translate numbers into more meaningful narrative values upon output. Both horizontal (group-to-group) and vertical (civilian group-to-actor) relationships can be defined. In the most recent model release, Athena 4, only essential services that do not require infrastructure are modeled explicitly (Figure 18). As shown in Figure 18,

"actors" control neighborhoods and are characterized by sets of goals, assets, strategies, and tactics.

Figure 18. A simulated environment as represented by Athena Project (Chamberlain, Duquette and Kahovee 2012, 2).



Both the IESE and the Athena tools provide examples of the types of tools into which a HISA product could be integrated.

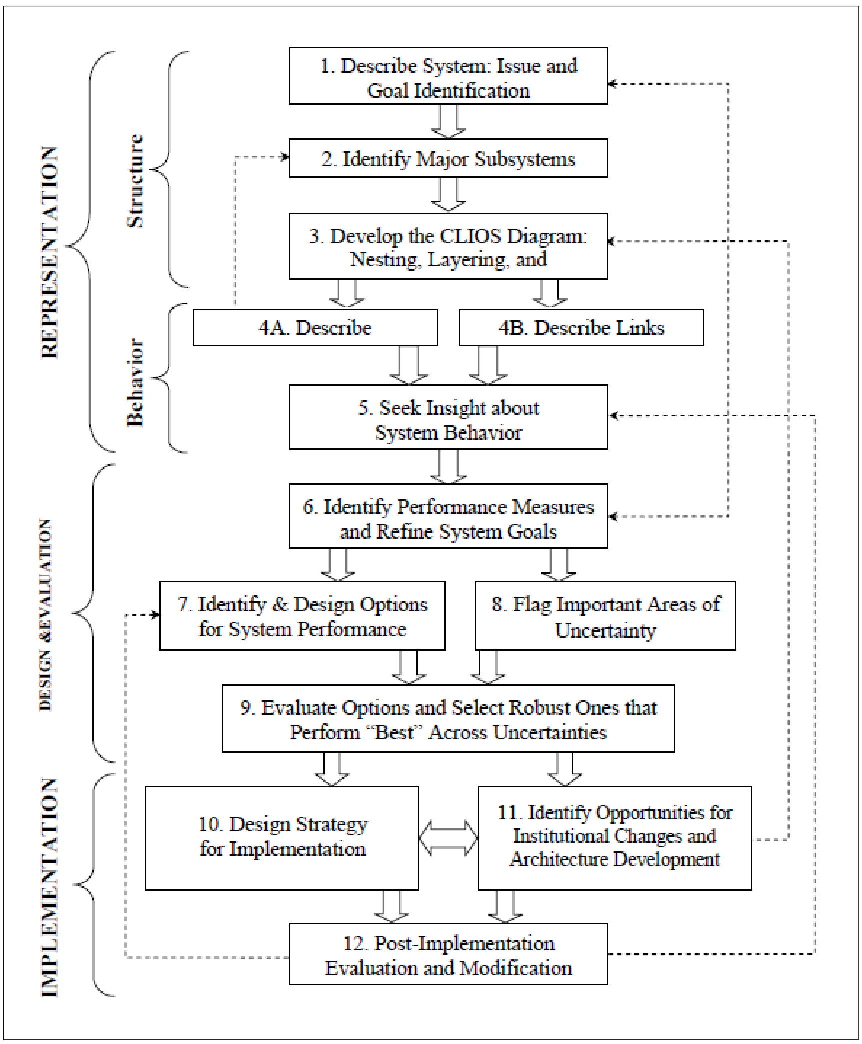
3.2.5 Naval Post Graduate School, Center for Infrastructure Defense

The Naval Post Graduate School's Center for Infrastructure Defense (CID) focuses on the continued operations of critical military and civilian infrastructure in the presence of accident, failure, and attack. CID maintains a robust network of researchers focused on: (1) determining how infrastructure systems will respond to major disruptions and (2) identifying optimal plans to invest limited resources (for hardening, redundancy, or capacity expansion) to make these systems resilient to worst-case disruptions. CID efforts often make use of the Naval Post Graduate School's capabilities in agent-based models, particularly for stability, security, transitions, and reconstruction (SSTR) operations. Agent-based models (ABM) are computational models that simulate the actions and interactions of small solvable problem sets that lead toward emergent behavior.

3.2.6 CLIOS/System Dynamic Models

Complex, large-scale, integrated, open systems (CLIOS) describe a class of systems that are of particular interest to the socio-technical domain in which infrastructure systems operate. A structured process to analyze the systems which explicitly includes the policy world as a part of the system is described, with an example application to the transportation system in a developing megacity (Dodder et al. 2004; Figure 19). The analysis uses a system dynamics approach to represent and explore physical subsystems, the institutional structure in which they are embedded, and the degree and nature of connections and feedbacks between subsystems.

Figure 19. Steps in a CLIOS process (Dodder et al., 16).



3.2.7 Retrospective interdependency studies

Retrospective analysis of infrastructure failures following catastrophic events provides one method of understanding the real-world implications of infrastructure interdependency.

The 2004 hurricane season brought five tropical storm systems to Florida, after which researchers interviewed multiple infrastructure providers and regulators about dependency manifestations across the electric power, water, wastewater, natural gas, petroleum, communications, and transportation networks, focusing specifically on Orange County, Florida (ARI 2006). The study binned the providers into four sectors: energy, water, transportation, and communication. These sectors were used to classify observed dependencies as (a) open-loop (e.g., energy > water when power outages prevented lift stations from being able to supply fresh water) and (b) closed-loop (e.g., energy > water > energy when the failure of electric lifts in a water distribution system led to the loss of cooling capacity in electric and gas utility computer systems and the need for a shutdown to prevent overheating). The study described examples of all types of dependencies and included failures as well as service bottlenecks and challenges. The study, however, did not include quantitative analysis on the numbers, types, severity, or relative importance of these different dependencies.

One approach to delineating dependencies using real world examples is, rather than an in-depth study following a particular incident, to use a larger but less detailed dataset derived from news reports of critical infrastructure (CI) failures. A database was compiled from public media sources that included a CI outage if it met three criteria: it occurred in Europe, it affected 10,000 customers or more, and it was not a scheduled operational occurrence (Luiijf et al. 2009; Figure 20). Data for 1,749 such occurrences between 2000 and 2008 were studied for dependencies and interdependencies. Events were categorized by infrastructure sector, and it was determined whether an event initiated a cascade of events, resulted from some cascade, or was independent (i.e., not directly caused by or directly causing any other event). The results showed that according to this database, the energy sector, followed by the telecommunications sector, were the primary initiators of cascades. Further, only two examples of a true interdependency were found; most cascades were unidirectional. This study may indicate that, unlike common assumptions of complex interdependencies used in theoretical analyses, cascading dependencies

are in practice shallow. This finding may reflect both reticulation (i.e., it is difficult to shut down all roads) and resilience (i.e., systems are built with backups) which may not be universal features of an infrastructure system. Because the source of the data was media reports, it also may be the case that cascading effects were significant but underreported because they were overshadowed by the primary failure.

Figure 20. Media-reported failure events categorized by initiating and affected CI sectors (Luiijf et al. 2009, 2).

	Initiating sector											
CI Sector	No sector	Energy	Financial Services	Government	Health	Industry	Internet	Postal	Telecom	Transport	Water	Grand Total
Education	1	1									2	4
Energy	515	65				4			2	1	3	589
Financial Services	34	5	3				3		15			60
Food	4	3								1		8
Government	27	17		1	1	1	4		14	1	1	67
Health	23	11			2				2		1	39
Industry	12	12				1				1	1	27
Internet	109	14					10		27			160
Postal Services	1											1
Telecom	170	62					1		57	5		295
Transport	294	98		1		3		1	5	15	5	422
Water	58	14				2					2	76
Total	1248	302	3	2	3	11	18	1	122	24	15	1749

A second database collected media reports on consequences of electrical outages in the United States, Canada, and Japan, and classified effects by affected infrastructure sector, impact type (economic, environmental, health, safety, social), severity, duration, spatial extent, and number of people affected (Chang 2009). Among 406 "significant" effects from five different outages, the social and economic impacts were termed "extensive" because they affected a large area and/or large number of people, while environmental, safety, and health impacts were labeled "intensive," because these impacts had severe but localized impacts (Figure 21). Environmental impacts (such as raw sewage dumping following power failure at treatment plants) tended to be both intensive

and extensive, though these events were few in number. Empirical studies such as these may be used to provide sanity checks on theoretically-derived interdependency networks.

Figure 21. Comparative impact and extent of infrastructure dependency failures (Chang 2009, 698).

Table 2. Prevalence of High-Impact and High-Extent Infrastructure Failure Interactions

	No. obs.[1]	% high Impact	% high Extent	% high Impact & high Extent	Ratio I:E[2]
BY EVENT					
2003 Blackout	78	41%	76%	17%	0.54
1998 Ice Storm	44	77%	27%	5%	2.83
2004 H. Charley	157	97%	12%	10%	8.05
2004 H. Jeanne	59	100%	3%	3%	29.50
2004 H. Frances	68	100%	3%	3%	34.00
BY DEPENDENT INFRASTRUCTURE SECTOR					
Communications	19	32%	68%	0%	0.46
Finance	6	50%	67%	17%	0.75
Transportation	33	82%	42%	24%	1.93
Utilities	67	82%	31%	13%	2.62
Government	18	89%	28%	17%	3.20
Food supply	31	84%	23%	6%	3.71
Business	58	86%	22%	9%	3.85
Health care	39	92%	13%	5%	7.20
Emergency services	58	93%	10%	3%	9.00
Building support	52	94%	10%	4%	9.80
Education	25	96%	4%	0%	24.00
BY IMPACT					
Social	56	68%	43%	11%	1.58
Economic	112	81%	29%	10%	2.84
Environmental	17	94%	24%	18%	4.00
Safety	57	91%	18%	9%	5.20
Health	164	91%	15%	5%	6.21

Notes: (1) "Significant" observations only (Impact and/or Extent are "high") (N=406)
(2) ratio of no. observations with high Impact to no. observations with high Extent.

3.2.8 Sandia, Los Alamos, and Argonne National Laboratories

Sandia National Laboratories, Los Alamos National Laboratory, and ANL have developed multiple models and simulations aimed at analysis and decision making for U.S. Homeland Security. Some of these efforts are summarized below.

The National Infrastructure Simulation and Analysis Center (NISAC) is a DHS-funded effort at both Sandia and Los Alamos National Labs that develops and uses multiple modeling and simulation techniques to analyze critical infrastructure interdependencies, vulnerabilities, and complexities, as outlined below.

- The NISAC uses system dynamics modeling to quantify and evaluate the following: the effects of infrastructure operations, the ability to meet demand given disruptions, changing conditions, and interdependencies.

- An Agent-Based Laboratory for Economics (N-ABLE) aims to capture complex supply chain and market dynamics to better understand vulnerabilities in U.S. businesses.

- Network modeling is used to represent transportation capacity under normal and disrupted conditions, as well as for telecommunications traffic.

- A complete national petroleum model for the United States has been developed to explore the availability of fuel in the event a component in the national supply chain is disrupted.

- A mapping application (FastMap[19]) browses U.S. infrastructure data from the Homeland Security Infrastructure Program (HSIP) Gold database[20] and produces reports of assets at risk, based on geospatial queries.

- REAcct (Regional Economic Accounting) is an accounting tool that provides a first approximation of economic impacts by sector and by county of a U.S. infrastructure disruption.

[19] FastMap is a fast algorithm for indexing, data-mining, and visualizing traditional and multimedia datasets.

[20] HSIP Gold database is a compilation of over 560 geospatial datasets, characterizing domestic infrastructure and base map features, which have been assembled from a variety of federal agencies, commercial vendors, and state partners. HSIP Gold 2015, in its entirety, is unclassified; it is subject to the handling and distribution rules for "Unclassified For Official Use Only" due to licensing and sharing restrictions set forth by the data source entities.

In addition to the previously described IESE software developed for DoD, other software developed at ANL is aimed at DHS users and includes the following:

- The *Critical Infrastructure Protection Decision Support System* (CIPDSS) is a system dynamics-based model that includes primary interdependencies between 17 critical infrastructure sectors.
- The *Interdependency Environment for Infrastructure Simulation Systems* (IEISS) is a tool that models interdependent energy networks and behaviors during disruptions. Outputs include state-level information of all components, lists of damaged components, and geographic areas affected.
- *Restore* is another model used to model complex and uncertain repair processes; it aids decision makers in choosing workarounds versus complete repairs and in estimating times to re-establish services.
- *NGReal-time* analyzes data available from private companies and published on the web to track and analyze natural gas delivery systems. This type of tool could be useful for extracting an infrastructure delivery data. *NGFast* is a rapid analysis tool to evaluate impacts of a natural gas pipeline break.

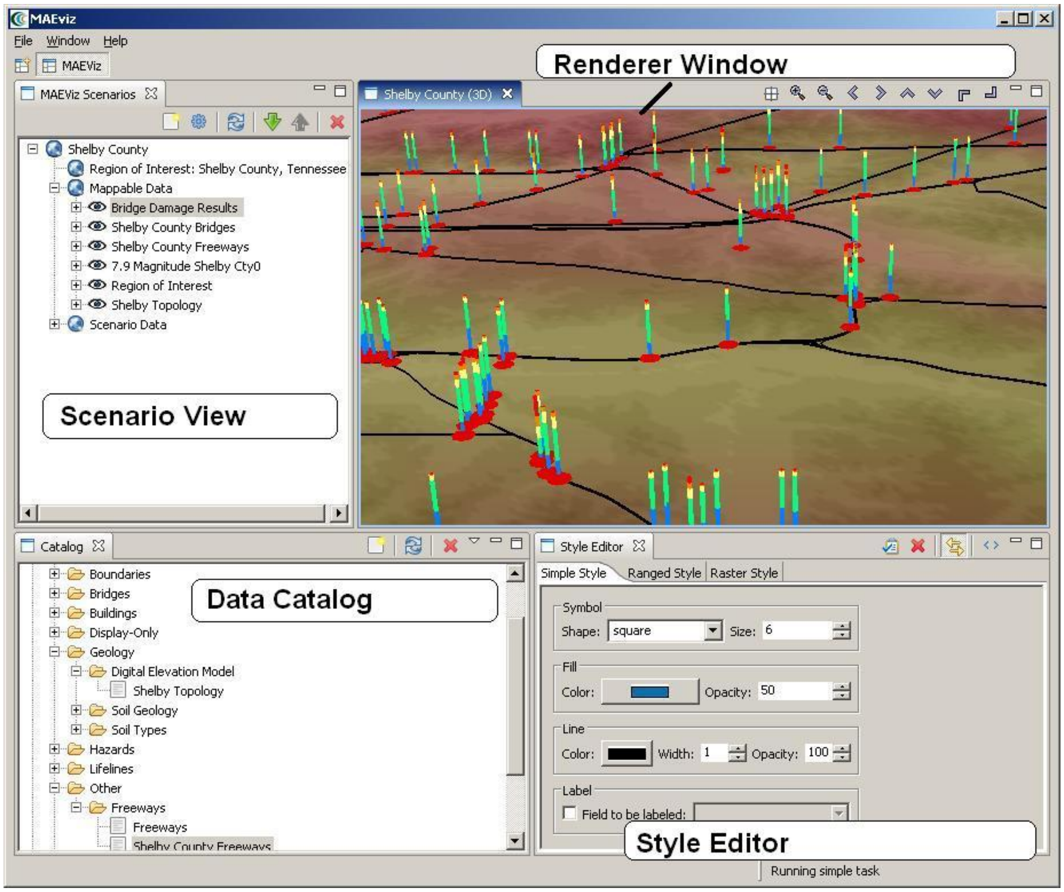
3.2.9 Multi-Hazard Approach to Engineering (MAE) Center

Housed on the campus of the University of Illinois at Urbana-Champaign and established by the National Science Foundation, the MAE Center is a research facility focused on integrating approaches necessary to minimize the consequences of future natural and human-made hazards. Integrated interdisciplinary research for: (a) synthesizing damage across regions, (b) estimating vulnerability across regional and national networks, and (c) identifying different hazards comprise the core research activities needed to develop a MAE and to support stakeholder and societal interests in risk assessment and mitigation. The MAE Center has developed software to help engineers, risk analyzers, and decision makers in various endeavors. All software may be downloaded from their website.[21] All MAE Center software employs the latest and most advanced workflow tools to provide a

[21] http://mae.cee.illinois.edu/

flexible and modular conduit through which the culmination of the interdisciplinary research and development efforts are integrated and delivered to end-users. Figure 22 exemplifies some of this software.

Figure 22. MAE Center software interface example (https://wiki.ncsa.illinois.edu/display/MAE/MAEviz+Building+Damage+Tutorial).



4 Sociocultural Assessment Frameworks

4.1 Ethnography

Ethnography focuses on discovering what people actually do and their perspectives while doing it. Ethnography means "writing about the *culture* of groups of people," and culture can be defined as the learned "beliefs, behaviors, norms, attitudes, social arrangements, and forms of expression that form a describable pattern in the lives of members of a community or institution" (Schensul, Schensul and LeCompte 1999, 21). For ethnographers, society is viewed as a system that encompasses the rhythm and pattern of daily social life, including economic and political relations, and the cultural underpinnings of these patterns. Ethnography is the signature tool of anthropologists. Since civil-military operators are engaged directly with communities on the ground, they are in a good position to practice ethnography (i.e., to observe behavior, obtain community perspectives, and be aware of the biases that can be introduced into the interpretation of data if scientific rigor is not followed). Ethnography has informed the development of social impact analyses, which provide guidance on what to observe in society regarding important sociocultural functions (Geertz 1973; Schensul, Schensul and LeCompte 1999).

4.2 Social impact assessment

Social impact assessment (SIA) offers a process that can be adapted for taking into account the role that infrastructure plays in society within the operational environment. In SIA, the current functioning of the community is taken as the baseline from which to assess potential impacts of a proposed action. The SIA process starts with identifying the problem associated with carrying out a proposed action in a particular community (e.g., a dam, road, power plant, or landfill site). SIA methodology includes the creation of a community and regional profile of the interested and affected parties, pressure groups, organizations, and institutions that will be impacted by the action (IAIA 2003, 234). This profile includes not only users within a service area per se, but also the social actors who are beyond the immediate service area but have a stake in the impacts of a change in service.

SIA leads to a determination in which sociocultural variables are the relevant variables for addressing the problem (among the universe of commonly used variables included in the SIA protocol). These sociocultural variables help to focus the baseline characterization of the sociocultural dynamics from which to determine the scope, magnitude, intensity, and duration of the potential impacts from the proposed action.

4.2.1 SIA processes

Each implementing authority has its own specific processes for conducting SIA and for determining which social variables should be considered. The International Association for Impact Assessment (IAIA) has endorsed the "International Principles for Social Impact Assessment" as being the official understanding of what an SIA should include. The International Principles were developed as an official IAIA project, with workshops to develop the principles held at various IAIA and other conferences across six continents over a five-year period. Several hundred people were consulted during the process, and some 50 people made substantial contributions to the document. The principles that followed are listed below (IAIA 2003, 233):

- Achieve extensive understanding of local and regional settings to be affected by the action or policy.
  - Identify and describe interested and affected stakeholders and other parties.
  - Develop baseline information (profiles) of local and regional communities.
- Focus on key elements of the human environment.
  - Identify the key social and cultural issues related to the action or policy from the community and stakeholder profiles.
  - Select social and cultural variables which measure and explain the issues identified.
- Identify research methods, assumptions, and significance.
  - Research methods should be holistic in scope (i.e., they should describe all aspects of social impacts related to the action or policy).
  - Research methods must describe cumulative social effects related to the action or policy.
  - Ensure that methods and assumptions are transparent and replicable.
  - Select forms and levels of data collection analysis which are appropriate to the significance of the action or policy.

- Provide quality information for use in decision making.
  - Collect qualitative and quantitative social, economic, and cultural data sufficient to usefully describe and analyze all reasonable alternatives to the action.
  - Ensure that the data collection methods and forms of analysis are scientifically robust.
  - Ensure the integrity of collected data.
- Ensure that any environmental justice issues are fully described and analyzed.
  - Ensure that research methods, data, and analyses consider underrepresented and vulnerable stakeholders and populations.
  - Consider the distribution all impacts (whether social, economic, air quality, noise, or potential health effects) to different social groups (including ethnic/racial and income groups).
- Undertake evaluation/monitoring and mitigation.
  - Establish mechanisms for evaluation and monitoring of the action, policy, or program.
  - Where mitigation of impacts may be required, provide a mechanism and plan for assuring effective mitigation takes place.
  - Identify data gaps and plan for filling these data needs.

Principles and Guidelines (IAIA 2003) is still the primary reference on conducting SIA, and it lists the following 10 steps in the SIA process (each step includes both interested and affected parties):

1. Develop public involvement program.
2. Describe proposed action and alternatives.
3. Describe relevant human environment and zones of influence.
4. Identify probable impacts.
5. Investigate probable impacts.
6. Determine probable response of affected parties.
7. Estimate secondary and cumulative impacts.
8. Recommend changes in proposed action or alternatives.
9. Develop mitigation, remediation, and enhancement plan.
10. Develop and implement monitoring program.

Additionally, multinational agencies and development banks publish implementation guidance for their SIA requirements. The World Bank has issued guidance since 1984 that has included social assessment. In 1991, the first official *Environmental Assessment Sourcebook* was published,

and it contained a section on social and cultural issues as part of environmental reviews. The UN Environmental Program (UNEP) produced an *Environmental Impact Assessment Training Resource Manual* (UNEP 2002). This comprehensive publication includes a chapter on SIA. The SIA information covered includes the role and scope of SIA in relation to environmental impact assessment (EIA), the types of social impacts relative to development projects, and the "principles, procedures, and methods that are used to assess and mitigate social impacts" (UNEP 2002, 492). The Asian Development Bank (ADB) offered general guidance for addressing social impacts of its projects in the 1993 *Guidelines for Incorporation of Social Dimensions in Bank Operations* (ADB 1993). This guidance has been supplemented by the 1994 *Handbook for Incorporation of Social Dimensions in Projects* that provides a more detailed look at project-level social considerations (ADB 1994). "The Handbook on Social Analysis: A Working Document" was produced by the Asian Development Bank in 2007, and it "provides a road map to specific ADB policies and procedures related to social development and social analysis" (ADB 2007, 5).

4.2.2 Criteria, variables, and indicators for data collection in the SIA process

The selection of criteria for analysis in the SIA process is a critical step that informs the quality and utility of the assessment. The criteria measure current status, but must be selected as to their ability to provide insight into future impacts. According to Branch, Hooper, Thompson, and Creighton (1984), "The important characteristics of the existing social environment are those that will either: (1) affect the characteristics of the proposed action or the responses made by the community to the proposed action or (2) be affected in an important way by the proposed action or by the responses made to it" (Branch et al. 1984, 86). The measurements associated with the criteria can be either quantitative or qualitative, and a good SIA will contain both. The same criteria can be used as the project progresses to monitor ongoing impacts and if needed, adjust mitigation strategy.

The 1994 *Principles and Guidelines* (IAIA) contained a set of 30 variables under 5 main categories. Rabel Burdge, a prominent figure in SIA research and a member of the committee that created the 1994 guidance document, published a list of 26 variables in similar groupings (in Vanclay 2002, 187). In 2003, the IAIA *Principles and Guidelines* provided an updated

list, which is still utilized. A comparison of the criteria variables are listed below in Table 5 (Kent 2010, 6–7).

Table 5. SIA criteria variables, original information taken from three sources, as indicated in header row (Kent 2010, 6–7).

Rabel Burdge	Interorganizational Committee	
1994 (as cited in Vanclay 2002)	1994 *Principles and Guidelines*	2003 *Principles and Guidelines*
Population Change (demographic effects)	**Population Change**	
Population characteristics	Population Change	Population size density and change
Dissimilarity in age, gender, racial or ethnic composition (ethnic and racial distribution)	Ethnic and racial distribution	Ethnic and racial composition and distribution
Relocated populations	Relocated populations	Relocating people
Influx or outflow of temporary workers	Influx or outflows of temporary workers	Influx and outflows of temporaries
Seasonal (leisure) residents	Seasonal residents	Presence of seasonal residents
Community and Institutional Structures (public involvement)	**Community and Institutional Structures**	
Formation of attitudes towards the project (voluntary associations)	Voluntary associations	Voluntary associations
Interest group activity	Interest group activity	Interest group activity
Alteration in size and structure of local government	Size and structure of local government	Size and structure of local government
Presence of planning and zoning activity	Historical experience with change	Historical experience with change
Industrial/commercial diversity	Employment/income characteristics	Employment/income characteristics
Enhanced economic inequities	Employment equity of minority groups	Employment equity of disadvantaged groups
Employment equity of minority groups	Local/regional/national linkages	Local/regional/national linkages
Changing occupational opportunities	Industrial/commercial diversity	Industrial/commercial diversity
——	Presence of planning and zoning activity	Presence of planning and zoning

Rabel Burdge	Interorganizational Committee	
1994 (as cited in Vanclay 2002)	1994 *Principles and Guidelines*	2003 *Principles and Guidelines*
Conflicts Between Local Residents and Newcomers	**Political and Social Resources**	
Presence of an outside agency	Distribution of power and authority	Distribution of power and authority
Introduction of new social classes	——	Conflict newcomers and old-timers
Change in the commercial/ industrial focus of the community	Identification of stakeholders	Identification of stakeholders
Presence of weekend residents (recreational)	Interested and affected publics	Interested and affected parties
——	Leadership capability and characteristics	Leadership capability and characteristics
——	——	Interorganizational cooperation
Individual and Family Changes (cultural effects)	**Individual and Family Changes**	**Community and Family Changes**
Disruption in daily living movement patterns	Perceptions of risk, health, and safety	Perceptions of risk, health and safety
Dissimilarities in religious practices	Displacement/relocation concerns	Displacement/relocation concerns
Alteration in family structure	Trust in political and social institutions	Trust in political and social institutions
Disruption of social networks	Residential stability	Residential stability
Perceptions about public health and safety	Density of acquaintanceship	Density of acquaintanceships
Change in leisure opportunities	Attitudes toward policy/project	Attitudes toward proposed action
——	Family and friendship networks	Family and friendship networks
——	Concerns about social well-being	Concerns about social well-being
Community Resources (infrastructure needs)	**Community Resources**	
Change in community infrastructure	Change in community infrastructure	Change in community infrastructure
——	Native American tribes	Indigenous populations
Land acquisition and disposal	Land use patterns	Changing land use patterns
Effects on known cultural, historical and archaeological resources	Effects on cultural, historical, and archaeological resources	Effects on cultural, historical, sacred and archaeological resources

As with any investigative research, each SIA will have a set of criteria selected for the specific project under review. The lists in Table 5 provide practitioners with variables that may be relevant in their application of the SIA process. These criteria remain applicable to many of the new, more wide-ranging research areas that utilize SIA.

4.2.3 SIA relevance to stability

SIA provides understanding about the social impacts of a proposed action so that policy makers can maximize positive effects and mitigate negative effects to the community (e.g., Sairinen 2009, 138):

> SIA refers to the process of assessing, predicting and managing the intended and unintended social consequences, both positive and negative, of planned interventions and any social change processes caused by those interventions. So, SIA is made for example in order to understand how a proposed action or environmental change will affect the life of residents, communities and regions and what are the potential impacts for gender and various social, ethnic and age groups.

Similarly, the assessment process used by military commanders to identify the impacts of infrastructure projects on society should enable awareness about the positive and negative impacts of military engagement on indigenous civilian society and on the military mission.

The nature of an impact relates to the sociocultural function associated with the impact. Representation of the intensity of impacts should take into account the differential effects of a proposed action on cohorts of age, gender, and socioeconomic class; vulnerable sectors of the population; social, cultural, economic, and political practices; and their association with critical functions of infrastructure in society. For example, for a power outage, one would want to determine the number of customers impacted. A calculation of number of customers in a service area could be a measurement for the magnitude of the impact of a power outage. However, this calculation does not account for the magnitude of the impacts of a power outage. Elderly, infirm, and infants in the service area affected by the power outage may suffer greater repercussions to health and well-being than healthy adults. Day-care centers, hospitals, schools, and offices within the service area affected by the power outage are more dependent on electrical power than stay-at-home parents for which the power outage is merely an annoyance (depending on the length of the

power outage). What if the power outage impacts the ability to celebrate a major cultural event, such as a wedding or a concert, which has been planned for a year prior to the event? In a conflict or post-conflict situation, duration coupled with intensity of the power outage takes on additional social, cultural, economic, and political significance, as witnessed by military operators and development specialists in Bosnia, Afghanistan, and Iraq.

Military approaches to characterizing the operational environment, for example ASCOPE (FM 3-57) or Joint Intelligence Preparation of the Operational Environment (JIPOE) analyses, also include an assessment of the social actors (e.g., individuals, organizations, interest groups), who interact within that environment.

Establishing a baseline of existing conditions for assessment purposes is a challenge within the contexts in which the Army operates. Military operations involve engagement in operational environments in which the local population may have experienced periodic violent conflict over decades as in South Sudan or Central African Republic, or frequent violent conflict as in Iraq or Afghanistan, or may be in a post-war situation as in Bosnia. In these situations, the role of infrastructure in daily life has likely been impacted by targeted destruction or neglect due to lack of funding or local expertise to maintain it. Assurance of reliable services and/or equitable distribution of services may not have been attainable due to lack of government or institutional capacity which was exacerbated by the effects of conflict. Therefore, for contexts of military engagement, the baseline for assessment should take into account how infrastructure functions as an engineered system and as a component of society, prior to the impacts of violent conflict.

For example, a baseline analysis for contexts of military engagement would consider questions such as:

- Before power plants that served cities were attacked in Iraq, which neighborhoods were served by the electricity produced?

- How can these neighborhoods be characterized in terms of socioeconomic status and ethnosectarian affiliation?

- What was the level of service?

- How was this level of service integrated into daily life?

- Who was the provider of the electricity, and what was the connection to the government?

- How did people not covered by this electrical service obtain it by other means (e.g. generators, opportunistic tapping into electrical lines)?

- How can the users of electricity who obtained the service by other means be characterized in terms of socioeconomic status and ethnosectarian affiliation?

Effective engagement necessitates an accurate understanding of the situation in the operational environment, which includes local-level and reliable information on sociocultural dynamics (e.g., social, cultural, economic, and political dynamics). In the vision for future military engagement, small units such as Special Forces or Civil Affairs and the Army's regionally aligned brigades will have long engagements in geographic areas of interest that are aimed at establishing stability and preventing further conflict. Engagement via the fixing and/or rebuilding of infrastructure is a common intervention by Army units involved in civil-military operations. Operational planners need to know how society was functioning before it was disrupted by violent conflict so that the effects of the disruption can be assessed and courses of action can be considered for how to re-establish or improve societal function.

4.3 Example social impact assessments

4.3.1 Sustainable livelihoods approach

Along with the expanded scope of SIA, there are new methodologies being developed to operationalize these new assessment fields. For example, a sustainable livelihoods approach to SIA is advocated by that focuses on community capitals (natural, economic, physical, social, and human) as factors in resiliency to change (Sadler and Coakes 2011, 323). Sensitivity to change is measured through the development of an integrated community resilience framework that shows interdependencies of the various capitals and results in a quantifiable baseline degree of sensitivity (ibid. 327, 329).

4.3.2 Consequence-based approach

Realizing that it is impossible to account for every conceivable threat, contingency planners have recently devised a new approach to risk assessment. Rather than focusing on threats, this new methodology ignores the cause of the disruptions and explores possible weaknesses in key operating elements. Known as "Consequence-Based Risk Assessment," this three-step model begins by identifying critical components. This analysis includes a review of infrastructure, staffing, key services, and other resources. Second, each identified element is examined and a determination made as to its capacity to operate in a stressful environment. Failure points are noted and strategies developed to compensate for these shortcomings. Last, all areas are reviewed and decisions are made to either leave as is (i.e., accept some level of risk) or invest in ways to increase the component's resiliency.

This approach dramatically simplifies the risk assessment process because rather than attempting to develop an exhaustive list of all possible threats, the planner can spend time understanding the capabilities and capacities of a limited number of operating components. Only elements that are identified as critical need to be reviewed. Once these critical components are analyzed, a decision can be made as to when and how to enhance them.

This approach is based on a conceptual framework that is currently used by the United Nations (UN) to quantitatively measure the degree of development in societies around the world. An example is the Human Development Index (HDI), where the level of human development is measured by: (1) human poverty index, (2) economic cooperation and development, (3) gender-related development index, and (4) gender empowerment measures.

5 Summary

5.1 Physical function of infrastructure

Of all the methods and frameworks highlighted in Chapter 3, those most relevant to HISA are summarized below.

The *SWEAT methodology* appears to be fairly entrenched in doctrine as a baseline infrastructure assessment methodology. Thus the advantage of its widespread dissemination should be utilized rather than trying to create a new physically-oriented infrastructure assessment method from scratch. Aspects of the SWEAT methodology may need to be expanded (e.g., to include non-electric energy sources). It should also be augmented with remotely collected data where that is available at appropriate scales, allowing for accurate assessments of the geographic extent of infrastructure reach and for its use by different components of society. Some important questions may only be answerable via these in-situ assessments such as state of maintenance, availability of parts, and likelihood of employees return following disruptions. It can safely be said, however, that ongoing in-situ infrastructure reconnaissance and assessment will be an important stream of information for efforts to understand the effect of infrastructure on subpopulations.

However, SWEAT is not sufficient for what we attempt to accomplish. We need to connect and provide the “back story” to the nouns in SWEAT/ASCOPE/PMESII. Each infrastructure sector and component likely has a tangled socio-political history, calling for an understanding of history and how it fits into existing socio-political narratives. Questions asked by EWB are relevant: What are the subgroups in a community? What power structures (and funding streams) exist? How can we know when the views of different groups have been included? USAID and TCAPF are also relevant with respect to infrastructure. Can we distinguish between needs, priority grievances, and sources of instability? Although we do not aim specifically to parse “instability,” this approach recognizes that not all needs will impact populations in the same way.

The *Rinaldi approach* that characterizes the six “dimensions” of infrastructure (including dependency characteristics) is an approach that is likely to be useful in developing a “typology” of socio-technical relationships. These dimensions could serve as a backbone structure on

which parameter sets for models could be developed. We may also decide to add new dimensions or aspects thereof to capture characteristics relevant to sociocultural considerations.

As part of an assessment of infrastructure effects, the short-, medium-, and long-term effects of different infrastructure types need to be considered. We need to expand our view of infrastructure systems from physical components that we can come in and build or rebuild and expect flawless operation and full use, to include the total environment that supports such systems, to include governance, financing, community interest, and operations and maintenance considerations. We need to incorporate storage capacity at all stages of distribution into a model that characterizes coupling of links, and quantifies risks from disruptions of different durations. If we aim to develop or repair an infrastructure, we need to also make sure to concurrently develop or restore a supply chain and maintenance capacity to support it. To do so, we may need to consider using non-standard technologies that may be appropriate to existing or projected supply chain and technical capacity characteristics. All these considerations may be supported by elements or new dimensions in the Rinaldi framework.

Like the two model described above, the *West Point model* suite also has several important strengths as well as some possible redundancies. The Components model has clear utility for HISA, as it provides modular categories for infrastructure functionality. However, the Coordination aspect of the Components model will by necessity have significant overlap with elements of the Environment model. Neither this model nor the Rinaldi model aim to create independent categories, and part of the goal of developing a functional modeling capability is to separate out which dimensions are truly required for a full representation of the human-infrastructure system.

The overall shape of the West Point model suite—a progression from an assessment of the environment, to specific infrastructure, to assessment of its condition and functioning, to the action-oriented development and protection models—provides a logical approach.

However, it is not within HISA's scope to provide suggested courses of action. The action-oriented models (e.g., SWEAT, Rinaldi, West Point), however, should still be incorporated into effects analyses, but the models

may not take the same form. Finally, the inclusion of the potential enemy point of view toward infrastructure assets and development is a feature that will need to be included in a HISA product.

5.2 Sociocultural function of infrastructure

Infrastructure is intricately intertwined in the functioning of society. Drawing from Chapter 4 of this document and for the purposes of sociocultural analysis, society can be viewed as composed of domains (e.g., social, cultural, political, and economic) that are linked in complicated ways that are often unexpected to a foreign observer. In the classical structural-functional approach of anthropology or social ecology, society can be conceived as a system of systems that function together but can be disaggregated for analytical purposes. Social impact and environmental assessment also rely on functional analysis to determine the baseline status of an area impacted by a project under consideration. Infrastructure is a human construct which enables and supports daily life from the individual to the global levels. Infrastructure is profoundly cultural in nature since the knowledge to produce it and the perception of need for it is shared by a community and transmitted over generations. Societies have developed a myriad of low-tech to high-tech infrastructures to serve a multitude of social, cultural, political, and economic functions. Even in the complex social landscape of a megacity, low-tech and high-tech solutions for infrastructure coexist contemporaneously and are interconnected in the functioning of society from the local to the global scale.

For the purposes of the HISA project, orientation to a baseline analysis shall be represented in an analytical framework, similar to the approach of SIA (IAIA 2003). This framework prompts a military user to consider the importance of the sociocultural function of infrastructure, and then aligns ethnographic analysis of the infrastructure sectors with the key questions indicative of important sociocultural functions of infrastructure. Ethnographic analysis is oriented to the sociocultural function of infrastructure in social, cultural, economic, and political domains. It results in the development of questions that point to those sociocultural dynamics that are significant to observe with regard to understanding the situation in the operational environment (Table 6).

Table 6. Description of domains and related key questions that point to significant dynamics in the sociocultural domain.

Social Domain	Key Question
Information sought about the social domain focuses on the activities of everyday life. Evidence from over 10 years of media reporting on the wars in Afghanistan and Iraq and recent academic research on population response to natural catastrophes indicate that people are basically concerned that once physical needs of food and water are met, the social relationships, routines, and habits of everyday life can be reestablished. An assessment on the sociocultural function of infrastructure should take into account how the use of infrastructure by significant social groups supports what the late French social scientist Michel de Certeau (1984) calls "the practice of everyday life."	How is the <*insert particular infrastructure sector*> used by social groups in everyday life?
Cultural Domain	**Key Question**
The cultural domain refers to the shared beliefs and customs of a community that are transmitted from generation to generation. The general sense of this definition is conveyed in FM 3-05.401 (para 3-37) in which culture is defined as "the learned and shared attitudes, values, and ways a populace behaves." Culture is expected to change over time. Recognizing how cultures change and interpreting the effects of that change is a significant component of ethnographic analysis. Although early ethnographies focused on local communities, a longitudinal perspective and a consideration of the effects of regional to global sociocultural phenomena are now acknowledged to be important to foster understanding about sociocultural systems. The tendency of Civil Affairs towards long engagements (through repeated deployments to areas of the world with a U.S. Department of State presence) lends itself to knowledge building about sociocultural dynamics from a long-term perspective.	How does the < *insert particular infrastructure sector*> function in the expression of culture by the social group?

Economic Domain	Key Question
Economics is generally understood to investigate the system by which goods and services are produced, distributed, and consumed. A formal, western economic approach is to assume that economic decision making is driven by the logic of rational choice among scarce means found in market societies. An anthropological view of economics seeks to discover how decisions about meeting material needs are culturally constructed in the complex environment of global to local influences (Gudeman 1986; Edelman and Haugerud 2005). Thus, economic behavior of interest occurs in the formal and informal economy as well as in a black market or illicit economy.	How does the < *insert particular* infrastructure sector> facilitate or constrain economic activities of the social group?
Political Domain	**Key Question**
A founder of the discipline of political science, Harold Lasswell, characterized the study of politics as the study of influence and the influential (Lasswell 1950:3). For political scientists, the influential tends to be the elite, which includes those who are directly involved in governing and those who are shaping the nature of governance. On the other hand, political anthropologists investigate the exercise of power in everyday life of local to global communities. From that perspective, infrastructure and the services it provides can be viewed as instruments of power for the provider of infrastructure. This perspective is informed by the work of Michel Foucault (1995), a French philosopher who writes about how power is exercised through prison architecture, which enables the prisoners to perceive that they are under constant surveillance, and thus power relations are ensured in the functioning of the prison. In this view, the infrastructure provider is able to exercise political power through the ability to determine what services are provided, and to control where infrastructure is put on the landscape and who has access to it. It suggests that the presence of infrastructure on the landscape and its association with the provider embodies the social contract that exists between the government (or other provider) and its constituents. Users of infrastructure within the boundaries of nation-states may benefit from services provided by the government, may choose to provide their own infrastructure, or may creatively exploit the infrastructure that is provided without paying user fees. Grievances may be expressed in various ways (e.g., complaints, stealing services, protests, riots, or destruction of property), by the users of infrastructure who are dissatisfied with the level or lack of service to which they feel entitled.	Which users benefit politically from the provision of infrastructure by the government or alternative providers of infrastructure and which are not?

5.3 Challenges

5.3.1 Data sources

Multiple data sources will be required to support a reasonably robust analysis of socio-technical links between infrastructure and the populations it serves. However, data source formats will typically be: local, privately or closely held, nonexistent, or excessively detailed (such as payment records), that are difficult to analyze. The scales of data that is available, either spatial or temporal, may not be appropriate to a given analysis. Equally important to records of existing physical infrastructure systems are records related to infrastructure management: resources, funding streams, actual facility use, quality of the output products, operations and maintenance, supply chain management, and technical education pipelines; however, these types of infrastructure records are typically harder to build a picture from than the physical infrastructure itself, which at least can be confirmed on the ground, if given appropriate access. Notwithstanding these challenges, HISA must make use of a smaller subset of areas (for which adequate data can be found) in order to build and populate models that can apply to similar situations where data may be lacking.

Local, provincial, and national government ministries, as well as public and private service providers, are a major, if potentially problematic, source of data. Meanwhile, according to FM 3-34 (2-13), “the current engineer force structure does not provide for personnel or equipment dedicated to reconnaissance efforts. This requires the engineer company commanders to form and train ad hoc teams for tactical reconnaissance tasks that focus on collecting technical information and performing a limited analysis.” To this end, a commander can define infrastructure data as a priority information requirement; one HISA outcome may be a capability to prioritize these requirements with respect to infrastructure. For example, in Iraq, USAID stated that schematic diagrams and routinely collected data such as flood levels have been useful in prior operations (USAID, 2014, 17). The report identified daily electrical power production (in megawatts) and daily crude oil production as two of the most successful indicators of infrastructure conditions on the ground, but it indicated that information on peak power, estimated demand, type of consumer use, and functionality of the distribution network were not available and would have required a complete supervisory control and data acquisition (SCADA) system, which was not in place. Load shedding

(the use of planned, rolling blackouts to distribute power) and illegal taps into power lines were common practices but largely unquantified.

Use of local records requires propriety and caution, and robust personal relations with host nation personnel are generally required to access this type of information. USAID, Civil Military Operations (CMO), U.S. Army Corps of Engineers (USACE) FESTs, or others can use SWEAT-type methodology to obtain data from observation, knowledgeable locals, and the host nation's engineering and government counterparts. Wright noted that SWEAT was extremely helpful, and he used both the model scores and written narratives were used. White recommended consistent use of the engineer reconnaissance smartcards from Appendix C of FM 3-34.170. He also noted that the CMO channels which produced this data at the community level were helpful sources of reporting and feedback in multiple areas, and that USAID presence enhanced situational awareness due to its longstanding relations with local and international NGOs. In support of future whole-of-government approaches, the DoD may wish to consider programs that match host nation engineers with USACE engineers and to create links with universities to perform joint analysis of infrastructure problems or train operations and maintenance teams. These activities could be initiated via Department of State or USAID, ideally prior to any kinetic operations.

Remote data collection can occur prior to presence on the ground, and should be used to augment SWEAT-type methods. Census data, though typically only decadal, can be used because it often contains basic information on household infrastructure and amenities by district. Data may also be provided by NGOs and international governmental organizations (IGOs) such as the World Bank. Some local governments and service providers have well-developed, web-enabled databases. For example, online or other public communication of load-shedding schedules may be used to parse an electrical distribution network, and records of payments and deliveries have been used to trace private fuel-supply networks. Other remote sources include imagery and other geospatial products, which can identify large structures such as generation and treatment facilities and can potentially be useful to estimate storage capacities of larger structures. Textual analysis and mining of open-source information could also yield incidental information about infrastructure maintenance and conditions. To use open-source media reports, a large collection and a long period of time is required to understand in what

sectors “positive” and “negative” events are occurring, and accounting must be made for potential bias and inequitable coverage.

5.3.2 Global transferability

Every location is different, and anyone can build a retrospective model for a specific location, given enough observations and a wide enough parameter space. This project aimed to generate a meaningful framework that can be efficiently tailored to anywhere on the globe. This objective presented challenges, as data sources are typically inadequate, inaccessible or costly to access, and non-uniform across many parts of the world, as discussed above. While coarsely aggregated indicators may not provide adequate information for decision making, finely detailed information can also overwhelm analytical capabilities. Our hypothesis is precisely that certain socio-technical relationships that are manifest in infrastructure systems will hold across societies, and that these relationships can be teased out by judicious application of existing information and modeling methods.

In the same way that the World Bank aimed to use a rapid survey to classify countries into groups in terms of their combined need for and ability to support infrastructure investment, we aim to establish a typology of countries or areas that have similar socio-technical infrastructure relationships. For example, a country might be characterized by relatively high levels of income from natural resources that flow to a relatively small fraction of the population which has historically made infrastructure funding decisions that principally benefit a particular subpopulation. Then, a system dynamics model showing the effects of infrastructure changes on these various subpopulations may also produce similar structures, parameter sets, and sensitivities across any group of nations that share a particular base characteristic, but associated maps, population information, and infrastructure datasets would be quite different in each case. Another set of countries (or areas) might be characterized by having a proliferation of smaller infrastructure projects that are supported by community or family groups which are largely unconnected to centrally planned infrastructure systems. Another country or area might rely heavily on external development funding for major projects, leading to a lack of an organic supply chain to support long-term operations and maintenance of that infrastructure.

Cultural and economically motivated habits of provisioning and storage of specific resources will also affect both demand for and use of infrastructure, and this information may be critical to planners. For example, if an electric supply is reliable, people don't invest in backup generation and therefore, the immediate effects of an outage might be more pronounced for that population than for a community used to making do with poor or irregular service. A model that represents these socio-technical characteristics can then output information about the point at which infrastructure disruptions become critical, and potentially how changes in infrastructure may create changes in both power structures and behaviors.

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14. ABSTRACT
The Army's understanding of infrastructure as an operational variable has been evolving over the past 30 years in response to significant events that range from international conflicts to domestic weather-related disasters. These experiences have combined to drive a significant shift in infrastructure doctrine, which now demands that commanders and staff understand, visualize, and describe the infrastructure variable in order to accomplish the Army's assigned missions of protecting, restoring, and developing infrastructure, all of which are missions essential to restoring stability after conflict or disaster. Current Army doctrine, however, does not say how commanders and staffs are to approach these challenging tasks. This report provides a focused examination of existing infrastructure assessment methods, models, and tools relevant to commanders' and staffs' growing need for utilizing a holistic analytical capability regarding infrastructure.

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